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Volume II (Oral Papers)

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Hyderabad, India

Organized by

Indian Society of Weed Science

In collaboration with

Indian Council of Agricultural Research
Directorate of Weed Research
PJT State Agricultural University

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Cover page: Major weed species in the Asian-Pacific region (in sequence): *Phalaris*, *Avena*, *Echinochloa* (croplands), *Mikania*, *Lantana*, *Alternanthera* (non-croplands), and *Eichhornia*, *Salvinia*, *Ipomoea* (water bodies). (Designed by: Mr. V.K.S. Meshram and Mr. Sandeep Dhagat, ICAR-DWR, Jabalpur, India)

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PREFACE

Weeds are a major biotic constraint in agricultural production systems worldwide. Besides reducing crop yield and quality, these unwanted plants adversely affect biodiversity, animal health and environmental security. In fact the problem of weeds is as old as the agriculture itself as almost all crop plants have been domesticated from their wild relatives only. Despite the development of weed management technologies, the weed related problems have been virtually increasing. This is due to adoption of so-called modern cultivation methods which also promote the growth of weeds. The threats posed by climate change, globalization, herbicide resistance development in weeds and commercialization of herbicide-tolerant crops are bound to accentuate the problem.

Realizing the growing weed infestations in the cropped and non-cropped lands, agricultural scientists of the world have been undertaking research and sharing their findings at various platforms. One such initiative was taken way back in 1967 when weed scientists of 22 countries of the Asian-Pacific region met at the Hawaiian Island of Kauai to establish linkages and discuss what should be done in weed science in this part of the world. This meeting led to the birth of the Asian-Pacific Weed Science Society, and since then, the Society has grown and developed into a major regional and international weed science society.

Over the years, the discipline of weed science has also developed in many countries of the region and professional societies dealing with the subject have been established for mutual exchange and sharing of knowledge. Besides organizing various activities including conferences and symposia at the national level, these professional societies have also been providing a platform for sharing of international experiences on emerging issues in weed science. The APWSS has been providing a major platform for these regional weed science societies for organizing the APWSS Conferences every two years. These Conferences have been organized in different countries of the Asian-Pacific region like Philippines (1969, 1983, 2003), Malaysia (1971, 1997), New Zealand (1973), Japan (1975, 1995), Indonesia (1977, 1991, 2013), Australia (1979, 1993, 2011), India (1981), Thailand (1985, 1999), Taiwan (1987), Korea (1989), China (2001, Vietnam (2005), Sri Lanka (2007) and Pakistan (2010) by the respective weed science societies. It is matter of great honour for the weed scientists of India to organize the 25th Asian-Pacific Weed Science Society Conference after a gap of 34 years since the 8th APWSS Conference was held at Bengaluru in 1981.

On the special occasion of the Silver Jubilee of the APWSS Conferences being organized at Hyderabad, India during 13-16 October, 2015, a series of publications were brought out on the status of weed science research in the Asian-Pacific region. This compilation is based on 155 oral presentations in 5 Satellite Symposia and 12 Technical Sessions of the Conference. A shortened version of each article is presented as Extended Summary highlighting the salient achievements made by the authors. The members of the publication committee (Dr. B.S. Chauhan, Australia; Dr. M.D. Reddy, Hyderabad; Dr. J.S. Mishra, Patna; Dr. G.N. Dhanapal, Bengaluru; Dr. Gita Kulshreshtha, New Delhi; Dr. C.T. Abraham, Thrissur; Dr. Sushil Kumar, Jabalpur; Dr. Shobha Sondhia, Jabalpur; Dr. K.A. Gopinath, Hyderabad; Dr. T.K. Das, New Delhi; Dr. C. Chinnusamy, Coimbatore; Dr. A.N. Rao, Hyderabad; Dr. M.B.B. Prasad Babu, Hyderabad; Dr. M.T. Sanjay, Bengaluru; Dr. Prashant Bodake, Nasik) and Convener, Dr. TVR Prasad under the Chairmanship of Dr. S.V.R. Shetty have undertaken the voluminous task of compiling, editing and presenting these articles in a systematic manner. It is hoped that this volume will be useful to scientists, teachers, students, administrators and policy makers who are concerned with weed management in their respective countries.

The financial assistance received from Research and Development Fund of National Bank for Agriculture and Rural Development (NABARD) towards this publication is gratefully acknowledged.

13 October, 2015

Dr. N.T. Yaduraju
President, APWSS

Dr. A.R. Sharma
Organizing Secretary

ACKNOWLEGDEMENTS

The Publication Committee of the 25th APWSS Conference is pleased to present the Volume II of e-Proceedings (oral papers) containing the general papers submitted by the weed science community for presentation in the Conference. For some of the members of the Publications Committee this is the second opportunity to participate in the editing of the papers received, the first being about 34 years ago when the 8th APWSS Conference was held at Bangalore, India. The Committee received a large number of papers covering a wide range of themes from 14 countries. The papers were reviewed by the members of the committee and others invited for both technical content and editorial quality. Additionally, the editors were requested to grade the papers for their quality so that priority could be given for higher quality papers for oral presentations. Given the large number of papers received and the short time period available, most of the reviewers completed the process of editing meticulously and on time. Some of the senior editors worked tirelessly always willing to take extra load and volunteering to complete the process of editing in a very short time period.

The Publication Committee noted that though the papers, in general, covered the main theme of the Conference well, the number of papers on weed control in individual field crops far outnumber than those on other sub-themes. Further, papers on chemical weed control / herbicides are many but very few papers focused on other control measures and habitat management approaches in integrated cropping/farming systems. The papers on other relevant sub-themes, such as economics, ecology, weed utilization, weed science education, participatory research are also minimal. It is hoped that some of these neglect areas / gaps would be addressed adequately during the Symposia and lead/plenary paper presentations. It was noted that large number of papers clearly highlighted the role of weed science in contributing to agricultural productivity. However, only a few papers focusing on other developmental challenges as biodiversity conservation, environmental degradation and climate change were received indicating that weed science addressing these global challenges is yet to be intensified in the Asian–Pacific region.

We thank Dr. N.T. Yaduraju, President, APWSS and Dr. A.R. Sharma, Organizing Secretary, 25th APWSS Conference for giving us this opportunity and providing their guidance and full support for bringing out these proceedings. We also thank all the authors for contributing articles for presentation at this prestigious Conference. Special assistance provided by Dr. Shobha Sondhia, Mr. Subhash Chander Singhariya and Mr. V.C. Tyagi of Directorate of Weed Research, Jabalpur in editing the proceedings is gratefully acknowledged. We admire the efforts of the team led by Mr. Gyanendra Singh in processing and formatting of all the articles, and bringing out the proceedings in a record time.

13 October, 2015 **Publication Committee**

Contents

Symposium – 1
Weed management in conservation agriculture

Optimising weed management in conservation agriculture in south-Asia using lessons learnt from Australian experiences

Conservation agriculture (CA) with crop residue or stubble retention and minimal soil disturbance (e.g. zero tillage) is very important for improving soil quality and productivity. However, this technology leads to increased dependence on herbicides and the rapid development of herbicide resistance. Resistance in *Lolium rigidum* in Australia has been one of the first and most dramatic examples of this problem. Research, development, extension and training (RDE&T) weeds programs have intensified in Australia to reduce the spread of resistance, and to integrate cost-effective and non-chemical (cultural and physical) options with herbicides for weed management.

In contrast, many smallholder farmers in Asia are still practicing aggressive tillage to grow crops. Lack of adoption of CA practices is likely due to many factors, including: lack of knowledge, complexity of the system and need for changed mindset, unavailability of suitable planting equipment, and limited access to herbicide technologies. In some countries rapid adoption of herbicides due to rising labour costs is leading to considerable risks of environmental pollution, human and animal safety, and the development of herbicide-resistant weeds. However, opportunities are arising to address some of these challenges and increase adoption of CA.

Research is needed to examine the role of the 'traditional' weed control tactics used in Asia in combination with herbicide tactics. Management of weeds is complex and requires a systems approach combining biophysical, social and economic elements to provide an enabling environment for uptake of new tactics. Innovation networks must link farmers, extension and researchers (agronomy, engineering, soils, social/economics and business), local suppliers and form partnerships between public and private sector organizations.

Sustainable weed management with herbicides and other tactics for CA in Asia can be informed by our experiences and 'lessons learnt' in Australia. The aim of this Symposium is to share knowledge and discuss the challenges and opportunities for managing weeds in CA to reduce threats of resistance, and ultimately decrease weed control costs for farmers in both Asia and Australia.

Conservation farming in southern Australia: a farmer's experience of managing herbicide resistance

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We began conservation farming in the late 1970s. The introduction of Sprayseed® (paraquat + diquat) enabled us to begin direct drilling without using cultivation as a method of weed control. It quickly became apparent there was no yield penalty from removing cultivation, and that there were benefits, such as improved soil structure and increased labour efficiency. Other new herbicides followed including glyphosate and in-crop herbicides such as Hoegrass® (diclofop-methyl). Alongside the increased use of nitrogen fertilizer, it was a golden era for growing crops and so we reduced livestock numbers and converted to continuous cropping and a true no-till system. The move to herbicide dependency occurred because they were very effective, relatively low cost and did not require a high level of management. Weed control in this system worked very well for a number of years. It was not obvious to us at the time that we had moved away from an integrated weed management system (IWM) that had diverse weed control methods such as cultivation, hay making, a pasture phase and lower soil fertility, to a system that was almost totally dependent on herbicides. We needed to implement a new IWM system, and one that utilized as many weed control methods as possible. This meant just not rotating herbicide groups, which at the time was regarded as IWM, but introducing non-herbicide methods of weed control. Over time we have added a number of non-herbicide methods of weed control, which has taken paddocks that had large problems with ryegrass back to paddocks that have very low populations. All of the IWM methods we use, by themselves are not capable of totally eliminating weed populations. To be successful, multiple non-herbicidal methods of weed control need to be used in conjunction with strategic use of herbicides to drive down the seed bank so the chances of herbicide resistance developing are much reduced. In our system it is too late for group A herbicides, but we are very aware of minimizing resistance developing in other herbicide groups, especially Group M, on which our conservation farming system is built. Through these various methods we have been able to keep ahead of herbicide resistance. In our experience, many of these strategies used in isolation will fail to control weeds to a level we desire. They are not silver bullets and we do see a rise in the weed seed bank when a technique fails. The fight to control weeds remains an ongoing challenge that requires constant surveillance and appropriate management. It is only when we combine multiple IWM methods with quality management that we see excellent results. We prefer to use weed management methods that give us multiple benefits, not just weed control. These benefits may include reduced inputs, lower risk, increased soil fertility, and ideally increased overall profitability. We have proven on our farm that depending only on herbicides for weed control is unsustainable. By introducing non-herbicide methods of weed control we can significantly extend the life of the products we already have while still having a profitable farming system.

Development of conservation agriculture and herbicide use in Australia

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Over the past two decades the Australian cropping landscape has been transformed by the shift from multiple cultivations of typically fragile soil to extensive use of no-tillage systems and crop residue retention. While soil erosion was a motivation for the development of conservation agriculture systems a number of economic drivers and enabling technologies led to the subsequent surge in use of no-tillage practices. The availability of cost-effective herbicide options was a major influencing factor on the rate of change. Lessons have been learnt about the role of herbicide and weed management in the development of conservation agriculture systems. Despite the challenges of extensive and continually increasing levels of herbicide resistance, Australian grain growers have kept in-crop weed populations and consequent crop yield losses due to weeds relatively low while also increasing the intensity of cropping. A recent study shows the range of herbicide and non-herbicide practices that are being used to achieve this. There is continued reliance on herbicides but also increasing emphasis on weed seed management. Australian grain growers have also demonstrated flexibility in the application of no-tillage and crop residue retention with cultivation and residue burning continuing to be used as weed control options. The results demonstrate ongoing successful weed control by Australian grain growers over a period of major farming systems change. What is also demonstrated is the need for flexibility and capacity to adapt when faced with the constantly evolving challenges of maintaining weed control in cropping-intensive systems.

Integration of alternative chemical and non-chemical approaches for weed management to ensure herbicide durability

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Australian farming systems rely heavily on conservation Agriculture (CA). Conservation agriculture removes most soil disturbance from the agricultural system and relies heavily on herbicides for weed control. The key benefits of CA are the retention of residue cover and reduction in soil erosion. As a result, there are gains in increased soil moisture conservation, soil biological activity and ultimately in crop production (Chauhan and Mahajan 2012). In addition, CA can reduce production costs in labour and fuel. However, weeds are a major constraint to conservation agriculture systems. Through the introduction of herbicides great gains have been made in crop and food production. However, as a result of over-reliance on herbicides, herbicide resistant and difficult-to-control weeds are now common-place across much of Australia's key cropping regions. This current situation has forced the Australian farming industry to 'think outside the square' in order to retain the benefits gained through CA, while achieving optimal weed control and crop production. In this paper, we discuss various chemical and non-chemical tactics being used in Australian agriculture to preserve the useful life of important herbicides and the need for their integration.

Weed management in conservation agriculture in Bangladesh

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Conservation agriculture (CA) is a resource saving, environment friendly crop production practice having minimum disturbance of soil, permanent soil cover and crop rotation. CA is becoming increasingly important in overcoming the problems of declining agricultural productivity both in developing and developed countries. This practice is a powerful option for meeting future food demands and maintaining the sustainability of agriculture. It is a newly practiced system in Bangladesh. Although CA reduces labour and fuel requirement and improve soil health, limited technical knowledge, unavailability of required machineries, lack of government policies, poor extension linkage, lack of awareness on herbicides use, insufficient research funding are the obstacles towards adopting CA in Bangladesh. Apart from all these limitations, weed could be considered as the major constraint to the adoption of this promising technology. Weed management in CA mostly relies on the extensive use of herbicides. Farmers are not aware of safe use of herbicides and therefore indiscriminate use of the chemicals could be hazardous to the environment and human health. Reports reveal that, repeated use of herbicides usually leads to the development of weed resistance to herbicides. Use of herbicides with alternate mode of action could be an effective approach to mitigate the problem. It is commonly believed that herbicides have adverse effects on environment. Adverse effects of chemicals on environment can be reduced by selecting appropriate herbicide and reducing herbicides use. The herbicide use could be reduced by integrating different cultural, mechanical and biological methods along with the herbicides. Therefore, well planned long-term research programs on weed management under CA needs to be developed to successful adoption of CA for sustaining crop productivity and protecting environment and soil.

Weed management in conservation agriculture in India

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Conservation agriculture (CA) involves minimum soil disturbance, permanent soil cover through crop residues or cover crops, and crop rotations for achieving higher productivity. Even though the adoption of CA in India is still in an early stage, it has been successfully used in the irrigated rice-wheat cropping systems of the Indo-GangeticPlains. Increased weed problems during the 'transition period' tends to be the most common hurdle in adoption of CA by farmers. Local research has shown that cover crops could play an important role in weed management in CA systems; however, their level of adoption at present is fairly low. Changes in patterns of tillage, planting systems, and other management strategies can alter the soil environment and lead to a major change in weed flora. Herbicide use has been an extremely important component of weed management in CA systems but greater effort is needed to integrate non-chemical weed control tactics with herbicides. Farmer-participatory model of research has proved highly effective in developing CA in rice-wheat system in the IGP. Ongoing efforts are required to increase the rate of adoption of direct seeded rice and zero-till wheat throughout the IGP. At present residue retention on farmer fields tends to be low. Greater awareness of the benefits of residue retention for improved soil health is worthy of an extension campaign in the IGP. Research effort needs to be enhanced to develop CA and promote its adoption in non-rice-wheat cropping systems in India.

Weed management in conservation agriculture in Pakistan

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In Pakistan, the main hub of CA is in the rice-wheat system. In this system, management of crop residues of both crops is a serious issue due to difficulty in the use of seeding machinery. There is need to develop and mass produce a seeding prototype which is locally suitable for low-horsepower tractors used in Pakistan for sowing operations. Moreover, for better weed management in CA in Pakistan, there is a need to develop more weed competitive cultivars of rice and wheat. In this paper, we discuss various farming and cropping systems being practiced in Pakistan, the history of development and adoption of CA in Pakistan, herbicide usage for weed management, and challenges associated with repeatable use of same herbicide, and changes in weed flora when switching from conventional to CA systems. Some effective weed control tactics are used in CA systems in Pakistan, the socio-economic influence on the adoption of CA technologies, and research, development, extension and training strategies for the future sustainability of weed management in CA systems in Pakistan are also discussed.

Symposium – 2
The weedy rice challenge in Asia: issues and options for management

The weedy rice threat to global food security in Asia

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Rice cultivation in Asia

It is universally acknowledged that rice is the world's most important food source and staple food for more than half of the world population. Asia is the world's largest rice-producing region (approx. 134 million hectares in Asia of a total of 153 million hectares globally). However, the ability to produce adequate rice for the ever-increasing human population will represent a major future challenge (Nguyen and Ferrero 2006). For example in Asia, the land area devoted to rice, the resources available, the breeding programs to produce rice varieties suited for multiple crops/year and rice yields appear maximised in several key rice-producing regions. At present, several factors as an increasing pressure on water resources, the expansion of urban and industrial sectors with subsequent competition for land, the increase in costs of labour, etc. have led to a major shift and change from flooded transplanted to direct-seeded rice (DSR).

DSR offers many advantages and opportunities, especially a greater water productivity and labour savings (Pandey and Velasco, 2005; Farooq *et al.* 2011). However, as in all major changes, there are some unforeseen negative outcomes. For centuries in Asia weed control was achieved by a combination of water management, laborious hand-transplanting of rice and hand-weeding. Weeds are a major constraint of DSR production because of the absence of the suppressive effect of standing water on weed growth at crop emergence. In DSR, hand-weeding is also more problematic because weeds are in far greater numbers and the size difference between weed and crop seedling is minimal (Rao *et al.* 2007, Chauhan and Johnson 2010). Thus, despite the greater availability of herbicides weeds remain a serious constraint which can cause major yield losses. Weedy rice (red rice), a conspecific weed of cultivated rice (*Oryza sativa* L.), is a significant problem throughout the world and an emerging threat in many Asian regions where it was previously absent (Table 1). For example, weedy rice infestations are increasingly reported in DSR systems in different countries including Malaysia, Sri Lanka, Thailand, India, Korea, Philippines and Vietnam.

The weedy rice problem

Weedy rices are broadly defined as plants from the genus *Oryza* that much resemble, mimic, infest and compete with rice (Delouche *et al.*, 2007). Weedy rice is reported as a serious pest of DSR systems. Weedy rice can spread rapidly, is highly competitive and can dramatically reduce rice yield and quality (Fischer and Ramirez 1993). The particular problem is that seeds of weedy rice species mature and shatter before rice, injecting large seed numbers into the soil seedbank. The shift to DSR accompanied by widespread, often exclusive, use of herbicides for weed control in rice can rapidly result in major problems with weedy *Oryza* species.

Due to many morphological and physiological similarities between weedy rice and rice plants the control is a difficult and complex long term endeavour. Pre-plant herbicides generally provide effective weed control of a major proportion of the soil weed seed bank and are much less expensive than hand weeding. However, selective in-crop control of weedy rice with post-mergence herbicide is extremely difficult as rice and weedy rice respond identically to herbicide toxicity. Post-emergence weedy rice control has been achieved with the use of herbicide-tolerant rice varieties. Thus, control tactics are based on multiple tactics to incorporate appropriate combinations of preventative, cultural, mechanical, chemical and genetic tools.

Table 1. Rice area (M ha) in selected Asian countries, Europe and USA, adoption of direct-seeded rice and year of first detection of weedy rice

Country	Rice ha (10^6)	DSR (%)	Weedy rice
China	30	10	1960s
India	44	30	
Indonesia	12	20	
Japan	1.6	1.6	
Malaysia	0.7	70	1987
Philippines	4.5	40	1991
Sri Lanka	0.9	80	
Thailand	10	35	2001
Vietnam	8	50	1994
EU	0.5	100	Early 1900
USA	1.4	100	1846

(Adapted from Vidotto and Ferrero 2005; Rao *et al.* 2007; Gressel and Valverde 2009; Matloob *et al.* 2014; Gealy *et al.* 2015)

In the face of the threat to rice production from weedy rice issues with DSR systems a number of management strategies have been established to be effective in rice ecosystems in the America's and Europe. The most convincing examples of appropriate weedy rice prevention and management have been deployed in Californian rice monoculture where weedy rice, accidentally introduced through contaminated seed, has been almost eradicated by the combination of water-seeding and the use certified crop seed free of weedy rice seed (Fischer 1999).

Can we reduce the negative impact of weedy rice in Asia?

Minimizing the negative impact of weedy rice, would significantly contribute to more profitable and sustainable rice cultivation in Asia. Thus, we have envisaged that the organization of a 'weedy rice workshop' would have helped to meet with prominent Asian rice weed scientists to collects their views and opinions on the rising challenges of weedy rice following adoption of DSR and issues related to cultivation of imidazolinone-resistant varieties in Asia and worldwide. The workshop focuses on topical issues of rapidly changing rice systems thourghout Asia, established preventative/management strategies (eg., use of clean seed, herbicides currently used, use of machinery, farm hygiene) and recent introduction of herbicide-related technologies in some Asian countries (eg Clearfield rice). We have reviewed some of the available and relevant research projects funded by the Australian Centre for International Agricultural Research (ACIAR) investigating how best management practices and solutions can improve the management of Asian rice systems towards greater productivity, profitability and sustainability with focus on a major constraint such as weed infestations and their control.

Potential innovative solutions to achieve safe and selective weedy rice control in rice crops by strategic and sequential application of the two components (the herbicide active ingredient + the herbicide safener) of commercially available herbicide formulations will be presented and discussed. In brief, some herbicides are toxic to germinating rice seedlings unless a specific herbicide safener is mixed with the herbicide compound in commercially available formulated products. Thus, we hypothesize the dissociated use of herbicide and specific safener will allow effective weedy rice control without causing injury to the rice crop (see also Shen *et al.* 2013). We hypothesize little damage or mortality in rice seeds exposed to the safener versus significant phyto-toxicity and mortality in rice seeds treated with the herbicide only. If our hypothesis will be confirmed we will be able to implement novel techniques for selective weedy rice control. It is important to emphasize that such a selective herbicide control of weedy rice in rice crops (herbicide ± safener) has never been achieved in commercial rice crops. Some preliminary results will be presented and their relevance discussed.

We aim towards a helpful and proficient satellite workshop on weedy rice as an important step towards increased awareness of weedy rice in Asia rice fields and possible control solutions based on improved understanding of weedy rice biology, physiology and biochemistry of the herbicide-weed interactions. Mutually beneficial research to Australia and Asia will be discussed as tested methodologies in rice crops can be applied to improve control of weeds in broad-acre Australian wheat crops.

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Weedy rice problem in direct-seeded rice systems

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Rice (*Oryza sativa* L.) is the most important staple food in Asia, where it is traditionally grown by manual transplanting of seedlings into puddled soil. However, growers are shifting towards direct-seeded rice systems, which are considered more profitable and sustainable than flooded transplanted rice because they require less water and less labour than the traditional method of transplanted rice (Chauhan 2012; Chauhan *et al.* 2012). There are mainly two kinds of direct seeding practiced in Asia: dry and wet. In dry direct-seeded rice systems, the crop seed is sown under zero-till conditions or after cultivation in dry soil conditions. In wet direct-seeded rice systems, pre-germinated rice seeds are sown (broadcast or drum-seeded) on the soil surface after puddling or cultivation in ponded conditions.

There are several advantages of direct-seeded rice systems, such as rapid planting operations, less labour and water requirements, and early crop maturity (Chauhan *et al.* 2012). However, weeds, including weedy rice (*Oryza sativa* L.), are the main biological constraint to the production of direct-seeded rice systems (Delouche *et al.* 2007, Azmi and Karim 2008; Chauhan 2013). In countries, such as Malaysia, Philippines, Sri Lanka, Thailand, and Vietnam, direct seeding is the dominant rice establishment method, in which weedy rice has become a severe problem. The main reasons for the association of weedy rice with direct-seeded rice systems are the absence of the suppressive effect of standing water on weedy rice, simultaneous emergence of weedy rice and cultivated rice, and the physiological and morphological similarities of weedy rice to cultivated rice (Chauhan 2013).

Weedy rices are unwanted plants of *Oryza sativa* that compete with rice. Weedy rice increases production costs and reduces growers' profit through yield reduction. The major traits of weedy rice are early shattering of the grain and variable seed dormancy (Delouche *et al.* 2007; Azmi and Karim 2008). In Asia, weedy rice was reported to have greater nitrogen-use efficiency for shoot biomass than cultivated rice (Chauhan and Johnson 2011). The use of contaminated planting seeds and weedy rice-infested equipment has helped in spreading weedy rice in several countries.

In a recent survey in Vietnam, weedy rice infestation was the worst problem encountered in wet direct-seeded rice; however, most growers were aware of the presence of weedy rice in their fields and the damage it does to the crop (Chauhan *et al.* 2015). In a previous survey in the Philippines, about 40% of the growers did not know that seeds of weedy rice have dormancy (Tanzo *et al.* 2013). In the same survey, cutting the weedy rice panicles at harvest was practiced by majority of the respondents (82%). Both of these studies suggested a need to increase awareness about weedy rice among Asian growers.

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Weedy rice - the Indian scenario

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Weedy rice (*Oryza sativa* f. *spontanea*) is a serious threat to sustainable rice production, particularly in direct seeded rice, as it affects crop production, harvest quality, and farmers' income. Infestations have increased with a shift from transplanting to direct seeding of rice, which is increasing to save water and labour, and reduce greenhouse gas emissions. To add to the problem, elevated CO_2 is found to enhance competition from weedy rice in rice production and reduce consumable rice production (Ziska *et al.* 2012)

Infestation in India

In India, weedy rice infestations of 5-60% in different states with 11.3 to 44.3% in cultivated fields have been recorded (Varshney *et al.* 2008) which is increasing rapidly. Agronomists from West Bengal also reported weedy rice infestations way back in 2009 (http://newsfromnadia.blogspot.in/2009/03/rice-production-may-fall-due-to-weedy.html). A yield reduction by 30-60% has been documented in rice agricultural fields of Kerela (Abraham *et al.*2012), depending on severity of infestations. Recently, Jharkhand recorded 24–32% infestation of weedy rice across Ranchi, Khunti, and East Singhbhum areas with as estimated yield loss of 10–45%. Heavy infestation of weedy rice is seen in eastern and southern India where direct seeding of rice is common though it is yet not a problem in Haryana and Punjab where paddy is cultivated through the transplanting method (Rathore *et al.* 2013).

Diversity amongst morphotypes

Phenotypic variations

Of the three hypotheses of origin of weedy rice, natural hybridization between cultivated and wild rice is largely accepted and validated. This conspecific taxon shares traits of both cultivated as well as wild rice types and thus, has several morphotypes. Genetic variations are expected but reports from Indian subcontinent in this context are rare. Weedy rice morphotypes collected from different geographical regions falling into different agro-climatic zones of India were collected and assessed for diversity based on morphological, physiological, and phenological variations in a common field experiment alongwith popular rice cultivars and wild rice. Statistical analysis revealed the morphotypes to cluster up with either cultivated or wild rice, or as an independent cluster.

Genetic variations

As phenotypes are expression of underlying genetic variations, genetic diversity amongst weedy rice accessions is expected. The Indian weedy rice morphotypes were assessed for available genetic diversity by molecular fingerprinting using rice SSR markers covering all 12 chromosomes of rice. Preliminary analysis reveals accessions to be diverse by 50%. Based on dendogram generated using NTSYS-pc and observations at 60% similarity, weedy rice clustered with cultivated rice or wild rice but was mainly an independent group. Weedy rice from the same geographical region was not necessarily genetically closer or similar to each other. Indian agriculture is witness to seed traffic of cultivated rice across agro-climatic zones, and hence morphological and physiological parameters may not associate to geographical boundaries.

Effect of climate change on weedy rice

To add to the problem, climate change is known to affect performance of rice, weedy rice and their interactions. Though initial reports have focused on the effect of elevated CO_2 on the crops recent understanding indicates that elevated temperature and CO_2, in combination, will affect the performance of rice (Desiraju *et al.* www.rkmp.co.in). With this background, studies were undertaken at the Directorate of Weed research, Jabalpur, to assess the effect of climate change on weedy rice. It was observed that the response of weedy rice to elevated CO_2 varies between morphotypes, even at the molecular level. Elevated CO_2 and temperature, in combination, affected the yield attributing parameters. Delayed maturity of panicles was also observed in morphotype and rice genotype studied.

Concerns

Awareness about the problem amongst farmers and management of weedy rice are the major concerns in India. Agricultural growers tend to categorize weedy rice as harmless 'off-types' and manage it by occasional manual rouging of panicles only. Farmers tend to abandon the land once it is heavily infested with weedy rice. With no selective herbicide available, land preparation practices are the sole method of its management. But farmers, by and large, restrict spending money on such fields and invest in other fields. Even the scientific community fails to recognize weedy rice as a potential problem and deals with it as merely introgressed material. This ignorance is a big reason for the increasing infestations of weedy rice in India. Weedy rice is a growing menace in direct seeded rice fields of India demanding urgent attention from multidisciplinary scientists to develop efficient technologies for its management.

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Enhancing awareness on weedy rice management in Iloilo, Philippines

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Weedy rice (WR) is a plant of the genus *Oryza* that infests and competes with rice. It is similar to cultivated rice in plant and seed characteristics, making it difficult to distinguish and in effect, manage when it has established side by side with cultivated rice. For the past years, rice production in Iloilo, Philippines has been increasingly affected by WR. Site visits in the province showed that severe WR infestation made rice farmers abandon their field. Interviews with local agricultural personnel showed their concern on how to efficiently manage WR. Informal talks with rice farmers sited faulty and inconsistent perceptions about WR thus they allow it to grow in their field. Suffice to say, the need to manage WR is essential before infestation becomes unmanageable in the province. It is important to establish farmers' level of knowledge on WR and how they manage it. Additionally, there is a need to identify the most effective control measures suited to local conditions. Both information are important inputs for developing educational resources that will enhance management of WR. Thus, it is tantamount that a combination of research and extension work on weedy rice is accomplished to enhance awareness. It is in this light that the study was undertaken.

METHODOLOGY

Research and extension work on WR were carried out focusing on two municipalities of Iloilo: *Dingle* and *Barotac Nuevo*. These are sites where WR are most prevalent in the province.

On-farm trials. The on-farm trials were conducted at the farmer's field of Dingle, Iloilo. The trials covered the Wet Season (WS) of 2010 and the Dry Seasons (DS) of 2011 and 2012. Each farmer's field was divided into two plots, with each plot measuring around 1000$m^{2.}$ One plot showcased the current farmers' practices (FP) for WR. The other plot was a demonstration of the Integrated Weedy Rice Management (IWRM) technology. Farmer's fields served as replicates.

Farmers' survey. To establish what rice farmers know with regards to WR, a survey was conducted. Two villages were purposely selected from Dingle and Barotac Nuevo, Iloilo with 90 rice farmers interviewed. Descriptive statistics were used in the analysis of the data.

Extension activities. Based on the results of the on-farm trials, farmers' survey and site visits**,** a communication team identified and developed the needed knowledge products in the areas. In addition, a rice production training with emphasis on WR management, was conducted for farmers and agricultural extension workers from both municipalities in 2012.

RESULTS

On-farm trials. With the use of IWRM practices, number of weedy rice seeds incorporated in the seeds during harvest was reduced compared with the FP. The reduction of contaminants was as high as 82% (2010 WS) when the IWRM and FP plots were compared. During the DS (2012), reduction of WR weeds was as high as 71%. This implies a reduction of seed contaminants in the seeds for the next cropping. Consistently, the number of weedy rice plants after three seasons was reduced using IWRM practices. The density at harvest of weedy rice plants during WS for the FP was as high as 16/m^2 (2010) unlike in the IWRM which has 2/m^2 only. During the DS, density at harvest went as high as 15/m^2 (2011) for the FP unlike for the IWRM which only has 1/m^2 (2012). The use of the IWRM technology may have resulted in lowering the infestation for the succeeding cropping seasons. Better yields were achieved in plots using IWRM. The IWRM plot achieved as high as 5.18 t/ha (2012 WS) which is almost 16% higher than that of the FP plot. The lowest yield achieved from the IWRM plot was 3.9 t/ha (2012 DS), which is still 15% higher than the FP. This might be possible because of the longer land preparation incorporated in IWRM thus reducing population and competition for other weed species present in the field.

Farmers survey. Survey results showed that farmers were confused on the major characteristics of WR as they thought that: (1) WR is a not a weed; (2) WR always have awns; (3) Flag leaves are always drooping; and (4) WR grains are all color red. With regards to knowledge of and practices with regards to WR management, majority of the farmers thought that: (1) early flooding, (2) deep plowing, and (3) clean irrigation canals have no effect on WR infestation. During local interviews, the farmers did not know the relation of these practices to WR management. On the knowledge on problems caused or effects of WR, majority of the farmers did not know that WR has an effect on milling cost and market value of harvested rice. Research studies showed that WR increases milling cost as the red layers or pericarp of WR grain need to be removed by extra milling and this extra milling resulted in broken grains (Smith 1981; Diarra *et al.* 1985). All these faulty knowledge may contribute to the poor management of WR and in effect, worsen the WR infestation.

Extension Activities. With the knowledge coming from the on-farm trials, survey and site visits, two leaflets and a video were produced focusing on presence of WR and its management. These were distributed to farmers and extension workers in Iloilo. Additionally, a two-day rice production training, with emphasis on the IWRM technology, was conducted to 100 farmers and extension workers from both municipalities. The training also raised awareness on the presence of WR and improved the participants WR knowledge. The researchers involve in the study served as main resource speakers.

CONCLUSIONS

The study showed the importance and benefits of using an integrated approach to manage WR. The advantage of this approach is that each control measure is already known to farmers and extension scientists. The collaborative work of the weed experts with the social science and communication groups also ensured that management and awareness on WR was achieved in the areas. Each group build on the work of the other and thus activities proved to be more focused and specific.

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Diagnostic survey of a rice-based cropping system in Vietnam with emphasis on weedy rice (*Oryza sativa* f. *spontanea*)

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Vietnam, with its rice-based agricultural economy, has been one of the leading rice-producing and -exporting countries in the world since 1989. The country has vast arable land, 82% of which is devoted to rice cultivation. The Mekong River Delta region is belonging to South part of Vietnam, covering about 4 million ha, is a major rice-producing area in the country. In 2008, 80% of the 17 million inhabitants in the Mekong Delta were engaged in rice cultivation, producing half of the country's total rice production. However, farmers in the Mekong Delta have, for a long time, been practicing direct seeding to establish their rice crop. Weedy rice infestation has threatened rice production in Vietnam, particularly in the Mekong Delta Region (Chin and Thi 2010). This problem was exacerbated by the shift in crop establishment method from transplanting rice to the wet direct –seeded rice (WDSR). The WDSR reduces the cost of inputs such as labour, time, and water prior to crop establishment in the field. Like other rice cropping systems, WDSR is beset by many constraints, foremost of which is weed (Chauhan 2012; Chauhan 2013). The idea is to generate basic information that would be the basis for coming up with new research agenda toward developing new strategies and technologies for the local communities. More specifically, the study reports farmers' familiarity with weedy rice (*Oryza sativa* f. *spontanea*), particularly the extent of weed occurrence and infestation in the region

METHODOLOGY

Diagnostic surveys were conducted in the localities of PhuocThoi (urban sub-district), Thoi Lai (rural district), and Co Do (rural district) in Can Tho Province, Vietnam, in 2012 and 2013 dry seasons. Can Tho, an important part of the Mekong Delta region, contributes a considerable portion to total annual rice production in Vietnam. A structured survey questionnaire was developed and pretested with three to four farmers from each locality. The final questionnaire focused on farmers' cultural practices such as the use of DSR, seedling establishment, land preparation, irrigation, fertilizer, and pesticide usage. Weed-related questions dealt with weed infestations and farmers' familiarity with weedy rice (*i.e.*, features of weedy rice and its management and control). A total of 102 farmer households (FH) (or 34 FH per district) were randomly selected and the members were interviewed using the local dialect by trained enumerators. The same questionnaire format was used for the 2012 and 2013 surveys.

The data were analysed and interpreted through descriptive statistics by ranking or paired t-test. The FH responses for each category or statement as percentage (or percent of surveyed farmers) for each year were averaged across the 102 FH. The percent values are enclosed in parentheses sans the % sign; for example, '(7/6)' refers to percent for '2012/2013', respectively. Where percentages are equal for the two years, only one value is presented

RESULTS

1.Knowledge of weedy rice attributes

The FH were aware that 'weedy rice is common in direct seeding' (97/99) and had very good 'knowledge of the attributes of weedy rice' (Table 1).

The FH agreed to these statements: 'weedy rice is a type of weed in rice', 'grains of weedy rice shatter easily', 'weedy rice can be taller than rice', 'grains of weedy rice are all coloured,' and 'it is possible to eat weedy rice'. Most FH (75), however, disagreed with the sentence saying that 'weedy rice can be harvested with cultivated rice'. Many respondents were not aware of weedy rice attributes as they relate to ecology and morphology *i.e.*, 'seeds of weedy rice have dormancy (86/82), 'longevity of weedy rice in soil can be more than one year' (64/54), 'weedy rice seeds left on the soil surface at harvest easily germinate' (32/56), and 'awns can be absent in some weedy rice' (47/54).

2. Knowledge of management/control of weedy rice by farmers at survey sites

· The FH agreed (Table 2) that 'weedy rice is hard to control in broadcast crops' (100/99). According to them, 'the use of clean seeds can reduce weedy rice problem' (100/98), and 'weedy rice problem will increase if seeds are shared with other farmers' (100/97). They perceived that 'manual weeding

Table 1. Farmer households' (FH) knowledge of attributes of weedy rice in PhuocThoi, Thoi Lai, and Co Do districts, Can Tho, Vietnam, 2012 (n = 102) and 2013 (n = 102)

Attribute	FH (%)					
	2012			2013		
	True	False	Don't know	True	False	Don't know
Weedy rice is more common in direct-seeding	98	2	1	99	0	1
Seeds of weedy rice have dormancy	14	-	86	18	0	82
Grains of weedy rice shatter easily	100	-	0	100	0	0
Weedy rice can be taller than cultivated rice	100	-	0	99	0	1
Weedy rice is a type of weed in rice	100	-	0	98	0	2
Awns can be absent in some weedy rice	52	1	47	45	1	54
Weedy rice seeds left on the soil surface at harvest easily germinate	53	15	32	44	0	56
Grains of weedy rice are all coloured	98	-	2	91	2	7

Table 2. Farmer households' (FH) knowledge of management/control of weedy rice in PhuocThoi, Thoi Lai, and Co Do districts, Can Tho, Vietnam, 2012 (n = 102) and 2013 (n = 102)

Management/control approach	FH (%)					
	2012			2013		
	True	False	Don't know	True	False	Don't know
The weedy rice problem will increase if seeds are exchanged with other rice farmers	100	-	-	97	1	2
Available herbicides may reduce the weedy rice problem	94	-	6	99	1	0
The best way to reduce weedy rice is to cut the panicles	-	100	-	-	-	-
Good land preparation (repeated tillage) can reduce weedy rice	100	-	-	45	42	13
Early flooding has no effect on weedy rice infestation	89	-	11	18	46	36
High seeding rate will reduce weedy rice	86	14		40	60	0
Thorough cleaning of farm machinery such as threshers /harvesters or tractors will help limit infestation of weedy rice	100	0	0.	92	6	2
Field or irrigation canals should be cleared of weedy rice to limit infestation.	100	0	0.	100	0	0
Repeated ploughing during fallow period can reduce weedy rice	31	13	56	24	13	64
Manual weeding is effective during serious infestation of weedy rice	93	4	3	95	2	3
Weedy rice is hard to control in broadcast crop.	100	0	0.	99	1	0
Weedy rice problems can be reduced by row seeding (use of drum seeder)	7	92	1	48	50	2
Use of transplanting can reduce the weedy rice problem	93	4	3	98	0	2
Use of clean seed can reduce the weedy rice problem	100	0	0	98	0	2
Use of water seeding can reduce the weedy rice problem.	42	3	55	29	3	68
Use of crop rotation can reduce the weedy rice problem	29	45	25	59	34	7
Continuous rice cropping can reduce the weedy rice problem	28	56	16	43	44	13

is effective during serious infestation of weedy rice' (93/95) but 'available herbicides may reduce weedy rice problems' (94/99). They were of the opinion that 'transplanting can reduce weedy rice problems' (93/98). Other control measures supported were 'clearing the field or irrigation canals of weedy rice to limit infestation' (100) and 'thorough cleaning of farm machinery like thresher/harvester or tractor to help limit weedy rice' (100/93).

3. Other weed problems and weed management

Fourteen species were reported as predominant weeds in the surveyed localities. More weeds were found in 2013 than in 2012. Across all sites, the most predominant weeds in 2013 were *Leptochloa chinensis* (L.) Nees, *Echinochloa crus-galli* (L.) P. Beauv., and *Oryza sativa* L. (contaminant rice variety).There were 14 weed species and *O. sativa*, as contaminants, reported, with seemingly heavier weed infestation in 2013 than in 2012. The most prevalent weed species in both years were *L. chinensis*, *E. crus-galli*, *Fimbristylis* species, *Cyperus iria* L. and *O. sativa*. The FH reported higher weed infestation in 2013 than in 2012 in spite of herbicide application plus hand weeding of their fields. The FH used either pre-or post-emergence herbicides or sequential applications of pre- and post-emergence herbicides, applied immediately after sowing up to 20 DAS.

CONCLUSIONS

The surveys, for two consecutive years, documented most details of cultural practices related to WDSR cultivation. The farmers revealed that they had very good 'knowledge of the attributes of weedy rice' and weedy rice is hard to control in broadcast crops' (100/99). Weedy rice infestation was the worst problem encountered in WDSR at the survey sites.

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Distribution patterns of weedy rice (*Oryza sativa* f. *spontaneae*) populations in different climatic zones in Sri Lanka

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Weedy rice (*Oryza sativa* f. *spontanea*) (WR) or "red rice "is one of the most nuisance weeds possessing higher morphological plasticity and mimic the wild and cultivated rice. The close morphological similarity makes it difficult to distinguish between WR eco-types and cultivated rice varieties in the field. WR was first reported in 1990 from Ampara District in Eastern Province of Sri Lanka and by the year 1997 it had become a serious problem in the area. Presently, WR is distributed in almost all agro-ecological zones of the country with varying population densities (Abeysekara *et al.* 2010). The studies related to the genetic diversity of WR populations and eco-climatic trend in distribution of WR are limited. Further, lack of such studies precludes the WR control and management in the country. In general, the distribution of weeds is facilitated by the changing climate (Hulme 2014). In the present study, it was attempted to employ agro-morphological and molecular data to recognize the distribution pattern/s of WR populations in different eco-climatic zones in Sri Lanka.

METHODOLOGY

Seeds of presumed different WR eco-types were collected from five different locations in each zone (Wet, Dry and Intermediate). Collected seeds and two wild rice varieties (*O. nivara* and *O. rufipogan*) were sown in plastic trays in a plant-house at the Open University of Sri Lanka. A total of five replicates of each eco-type were planted in plastic pots with representative paddy soils from each location. Replicates were arranged in Complete Randomized Design (CRD). Agro-morphological characterization (using thirty six characters) of WR eco-types and cultivated rice varieties were measured using the Standard Characterization Catalogue of PGRC, 1999**.** Total genomic DNA was extracted from 7-day old seedlings of respective WR eco-types, wild rice and cultivated types using Ceygen Plant total DNA purification kit. A total of ten SSR primer pairs were used (Table 1) for molecular study. SSR markers were obtained from Gramene (http://www.gramene.org/). A four-primer system was used, which included a universal M13 oligonucleotide (TGTAAAACGACGGCCAGT), labeled with one of four fluorescent dyes (6-FAM, NED, PET or VIC). Fluorescent dyes allow the products to be four plexed during electrophoresis; a special forward primer composed of a concentration of the M13 oligonucleotide; and the pig tail reverse primer for SSR PCR amplification. All amplification reactions were carried out in a total volume 30µl of which consist 1 x PCR buffer, 1mM dNTPs, 2µM SSR primers, 2mM $MgCl_2$, 50ng of genomic DNA and 0.5 Units of Taq polymerase. SSR alleles were resolved on an ABI Prism 3100 DNA sequencer using Gene Scan 4.1 software, and sized precisely using Gene Scan 600 LIZ ladder. Fragment analysis using capillary electrophoresis was performed using GENE MAPPER software and identified different peaks among WR eco-types and wild rice varieties. The data collected from WR eco-types, wild rice and cultivated rice was subjected to PCA with 'varimax rotation' in SPSS/PC Ver. 20.

Table 1. Ten SSR primer pairs used for the study

Oligo name	Oligo sequence (5'- 3')
M13RM11F	TGTAAAACGACGGCCAGT TCTCCTCTTCCCCCGATC
PigtRM11R	GTTTCTTATAGCGGGCGAGGCTTAG
M13RM14F	TGTAAAACGACGGCCAGTCCGAGGAGAGGAGTTCGAC
PigtRM14R	GTTTCTTGTGCCAATTTCCTCGAAAAA
M13RM21F	TGTAAAACGACGGCCAGTACAGTATTCCGTAGGCACGG
PigtRM21R	GTTTCTTGCTCCATGAGGGTGGTAGAG
M13RM 44F	TGTAAAACGACGGCCAGTACGGGCAATCCGAACAACC
PigtRM44R	GTTTCTTTCGGGAAAACCTACCCTACC
M13RM84F	TGTAAAACGACGGCCAGTTAAGGGTCCATCCACAAGATG
PigtRM84R	GTTTCTTTTGCAAATGCAGCTAGAGTAC
M13RM167F	TGTAAAACGACGGCCAGTGATCCAGCGTGAGGAACACGT
PigtRM167R	GTTTCTTAGTCCGACCACAAGGTGCGTTGTC
M13RM205F	TGTAAAACGACGGCCAGTCTGGTTCTGTATGGGAGCAG
PigtRM205R	GTTTCTTCTGGCCCTTCACGTTTCAGTG
M13RM211F	TGTAAAACGACGGCCAGTCCGATCTCATCAACCAACTG
PigtRM211R	GTTTCTTCTTCACGAGGATCTCAAAGG
M13RM280F	TGTAAAACGACGGCCAGTACACGATCCACTTTGCGC
PigtRM280R	GTTTCTTTGTGTCTTGAGCAGCCAGG
M13RM332F	TGTAAAACGACGGCCAGTGCGAAGGCGAAGGTGAAG
PigtRM332R	GTTTCTTCATGAGTGATCTCACTCACCC

RESULTS

The pattern reflected from PCA on variation of agro-morphological characters of WR eco-types, wild and cultivated rice varieties revealed that agro-morphological characters were broadly vary between different rice eco-types in climatic zones with certain degrees of overlapping of groups of Wet- and Dry-zone-WR eco-types. WR eco-types

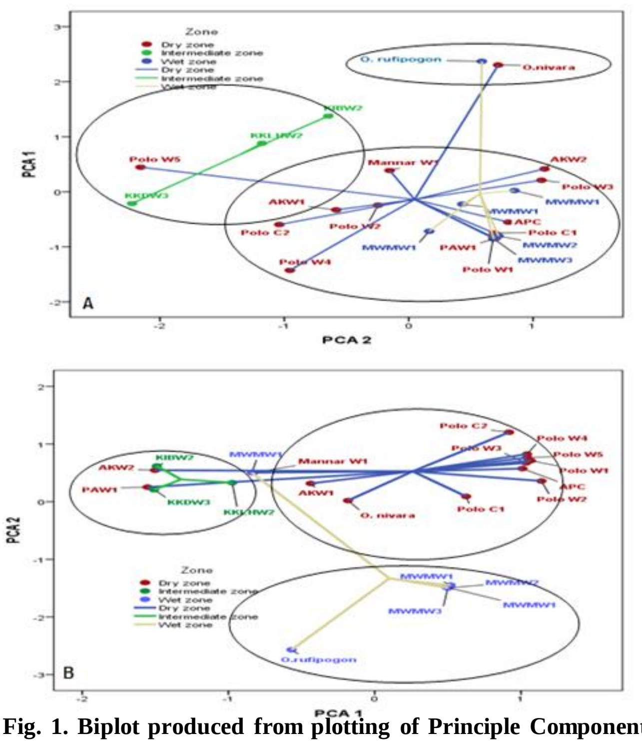

Fig. 1. Biplot produced from plotting of Principle Component scores of axis 1 and 2 from the analysis of; A. agro-morphological data (percent of variance explained = 32.9%), B. molecular data (percent of variance explained = 44.4%)

occur in Intermediate zone were clustered into a group (Fig. 1A). Distribution of agro-morphological characters of WR, wild and cultivated rice showed a weak trend with climatic zones indicating the plasticity of morphological features of WR enabling them to grow in any agro-ecological zone. Molecular data on PCA displayed a distribution pattern of WR eco-types and wild rice falling into groups reflecting their eco-climatic provenance (Fig. 1B). Distribution pattern of wild rice *O. nivara* which is restricted to Dry zone is associated with dry-zone-WR and cultivated rice varieties suggesting a possibly origin from *O. nivara*. Further, WR eco-types associated with *O. rufipogon*, common in Wet zone could be assumes as a contributive wild rice for origin of WR eco-types in Wet zone. WR populations in Intermediate zone showed closer affinities to *O. nivara* suggesting that they possibly hybridized with *in situ* cultivated rice.

CONCLUSION

WR populations in different climatic zones of country are sporadically originated in the respective ecological zones associated with, *O. nivara* for Dry and Intermediate zone; O. *rufipogon* for Wet zone WR ecotypes.

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Present status and management approaches of weedy rice in Japan

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Asian rice crop (*Oryza sativa* L.) was domesticated from wild rice (*O. rufipogon* Griff.). Hybrid plants are sometimes found growing in the same habitat around rice fields. In this report weedy rice is a generic name indicating various types of the above rice species which perform as a weed and infest rice crops. Although weedy biotypes of common wild rice often grow in rice fields, weedy rice infesting rice crops has more detrimental effects such as mimicry to rice crop, tolerance to rice herbicides similarly to the crop, and adaptability to rice fields.

In Japan rice is mainly transplanted by machinery, while direct rice seeding is restricted to a small area (25,889 ha, 1.6% of rice area 1,597,000 ha in 2013). Weedy rice problems, however, are increasing. Two types of problems caused by weedy rice are reported from different regions. One is the contamination caused by red pericarp of weedy rice types found mainly in wet seeded rice systems. The other problem is caused by white weedy rice types which are characterized by very easy shattering in dry seeded rice.

Red rice contamination

Contamination with pigmented rice reduces the rice price and income of the farmers. According to the national rice inspection system, very low contamination of 0.01% will result in lower grading. Farmers cannot ignore even the very low contaminations. Weedy red rice was historically called by the local name "TOUKON" in the region. This means that the red weedy rice problem has been a long lasting problem. Various red weedy rice plants were sampled and classified into the several biotypes by their morphology and physiological characteristics. Rice farmers usually can distinguish the weedy rice plants from rice cultivars by their morphology. Weedy rice plants are generally taller than rice cultivars and flower several days later. The color of grain husk becomes darker gradually during ripening stage. However identical types also exist in the fields. Farmers were advised to remove the mimic types by their grain tip color often genetically relating to their pericarp color. NARO Agricultural Research Center (NARC) assessed various weedy rice samples from fifteen prefectures after 2000 to 2014. Very recently red rice contaminations have occurred in several regions where direct seeding was not practiced. Our investigation suggested that the identical types seem to cause the problems.

White weedy rice with high level of shattering

It is very difficult for rice farmers to recognize white weedy rice in their fields at early stage of the infestation. Yield losses can be up to 60% when heavy infestations occur in dry seeded rice. Eco-physiological studies reveled that both of *indica* and *japonica* ecotypes were detected in these weedy rice samples in the area (Usiki *et al.* 2005). Studies on relationship between the weedy rice accessions and rice cultivars suggested japonica weedy rice closely resembled each corresponding cultivars almost all characteristics with exception of grain shattering (Akasaka *et al.*, 2009). Their pericarp is white as same as cultivars. So the weedy rice infestation could be missed by farmers when the level of infestation would is low.

Weedy rice management

Increase of weedy rice in transplanted rice seems to be due to widespread use of selective rice herbicides highly safe to the crop with little to none activity against weedy rice. Rice farmers usually use very safe rice herbicide only one time in the season achieving effective control of rice weeds. For example, sequential applications of the effective herbicide pretilachlor in transplanted rice help to much reduce weed infestations, although this has little efficacy in controlling weedy rice. To solve the problem of weedy rice, alternatives are being considered and studied as part of an integrated weed management (IWM) approach.

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Herbicide resistant weeds in Malaysian rice fields: Will weedy rice become the next candidate?

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Malaysia is among countries facing herbicide resistance problem, mainly in plantations, vegetable farms, and rice fields. To date, 15 weed species have now been identified to develop herbicide resistance, which 7 resistant species are found highly infesting many rice fields; predominantly to synthetic auxin or/and ALS-inhibiting herbicides. However, weedy rice (*Oryza sativa* complex) has been recognized as the most problematic weed in almost all rice granaries. In late 2010, two non-transgenic, locally developed imidazolinone-tolerant (IMI-TR) rice varieties, namely MR 220CL1 and MR 220CL2, together with the technique known as Clearfield Production System (CPS) were officially launched to overcome weedy rice problem (Azmi et al. 2012). Unfortunately, the repeated use and sole dependence, as well as ignorance on the appropriate use of CPS has caused a new problem in weedy rice, which is the risk of developing resistance to this herbicide.

METHODOLOGY

Weedy rice seeds were collected from weedy rice plants reported to survive the application of CPS IMI-herbicides in the fields that have been planted with CPS rice for more than 7 planting seasons in 3 townships in Kedah State (Table 1). Preliminary resistance potential testing was done using a single dose herbicide. Seed bioassay experiment was conducted using 9-cm-diam petri dishes in a completely randomized design, replicated four times. Twenty seeds of weedy rice from three reported fields and a known susceptible weedy population rice were placed on two sheets of filter paper (Whatman #1) in each petri dish. Five-milliliter aliquots of aqueous emulsions of commercially formulated imazapic (52.5%) + imazapyr (17.5%) were applied to each petri dish at rate of OnDuty™ 220 g/ha (similar to 0.58 g imazapic + 0.19 g imazapyr per 1L of water). Control treatment was applied with distilled water. Petri dishes were incubated in the dark in a growth chamber at 20 C. Seven days after treatment, the percentage of germination, shoot and root lengths of each seedling were measured.

In a pot experiment, twenty five pre-germinated weedy rice seeds were seeded at a depth of 1cm in 25cm x 35cm plastic trays. When seedlings reached the 2-leaf stage they were carefully thinned to 20 per tray. Plants were sprayed at 3-4-leaf stage with imazapic+imazapyr at rate of 220 g/ha using a knapsack sprayer. All trays were arranged in a glasshouse in randomized complete block design with three replications. Conditions of water before and after spray followed the herbicide recommendation label. Twenty-one days after treatment, the percentage of survival and dry weight were taken.

Table 1. Growth responses and resistance potential of three weedy rice populations to imidazolinone herbicide

		Seed bioassay			Whole-plant test
Weedy rice population	Treatment	Germination (%)	Shoot length (cm)	Root length (cm)	Survival (%)
Suceptible	Distilled water	100.0	3.1	2.5	100
	Imazapic+iiazapyr – 220 g/ha	10.0	0.1	0.1	0
Kg. Sungai Limau	Distilled water	100.0	3.8	4.2	100
	Imazapic+ imazapyr – 220 g/ha	58.7	0.5	0.4	96
Kg. Simatang Pinang	Distilled water	100.0	3.8	4.0	100
	Imazapic+ imazapyr – 220 g/ha	53.7	0.5	0.5	20
Kg. Simpang Sanglang	Distilled water	100.0	5.5	5.4	100
	Imazapic+ imazapyr – 220 g/ha	67.5	0.6	0.56	60

RESULTS

It was clear that the CPS IMI-herbicide failed to provide adequate control of weedy rice in both tests. Weedy rice collected from Sungai Limau exhibited the highest survival in both pre (58.75%) and post- (96%) imazapic + imazapyr applications, respectively (Table 1). This was followed by weedy rice collected from Kg. Simpang Sanglang, whereas the lowest survival was recorded from Kg. Simatang Pinang. From this preliminary findings, it shows that these weedy rice populations have developed resistance to CPS IMI-herbicide at different levels. Evidently, in a different experiment, it was also found that the progeny of weedy rice plants grown at a close distance to IMI-TR rice exhibited a certain level of tolerance when sprayed with Clearfield IMI-herbicide (Mazlan *et al.* 2014). Further national scale sampling and herbicide screening is required to confirm this incident.

CONCLUSION

It is most likely that the occurrence of resistance in weedy rice to the IMI-herbicide has already taken place in the Malaysian CPS rice fields. Without appropriate management, this weed is likely to become the next and major herbicide resistance weed problem in Malaysian rice fields.

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Clearfield™ rice: key challenges on a global perspective and lessons to be learnt in Asia

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Controlling weedy rice (*Oryza sativa* L.) during the rice growing season is made possible with Clearfield rice™ technology, which allows the application of imidazolinone herbicides (imazethapyr, imazamox, imazapic, imazapyr) to rice. The technology is highly effective and is an excellent tool to have in direct-seeded rice systems. It has resulted in significant yield increases in areas that were otherwise rendered unproductive by severe weedy rice infestation. However, in cases where there are weedy rice escapes, hybridization between the weed and the crop occurs and ALS-resistant weedy rice arising from pollen flow has been documented in regions where Clearfield™ rice is grown. Volunteer herbicide-resistant rice is also becoming a problem. If the situation is not mitigated, then the field will revert to severe infestation; this time with a population that could no longer be controlled with existing rice herbicides. This problem is expected to be greater in Asia than in North America because of several factors. The greatest challenge with herbicide-resistant rice technology is gene flow mitigation –optimizing weedy rice control, minimizing crop-weed hybridization, minimizing gene flow by seed, and crop rotation. All of these are complex principles to implement. Closely related to this is the selection for resistance to ALS herbicides in other weed species in rice. We are now observing increased cases of ALS-resistant *Cyperus* spp. and *Echinochloa* spp. Selection pressure can be reduced by keeping a diverse production system. Diversification of the rice production system while utilizing herbicide-resistant rice technology is another great challenge. These daunting challenges can be overcome only if all sectors involved in rice production (government, private industry, academia, farmers) work together.

It has been 13 years since Clearfield rice™ was commercialized, primarily to control weedy rice with imidazolinone herbicides. Clearfield rice™ is a nontransgenic, herbicide-resistant (HR) rice, produced by mutagenesis and classical breeding (Croughan 1998). It was launched almost simultaneously in the southern US, Latin America and South America, offering a novel opportunity to control weedy rice selectively in rice. Clearfield rice™ was launched in Malaysia. Technology adoption was rapid wherever it was introduced, reflecting the great void that the technology is able to fill. In the USA, Clearfield rice™ was initially recommended either with a pre-emergence (PRE) application of imazethapyr at 4 oz ai/A followed by a second application of the same dose to V2-V3 rice. Alternatively, imazethapyr could be applied sequentially early post-emergence (POST), at the same dose, and a second dose one to two weeks later. The Clearfield™ program eventually evolved to include other soil-active herbicides clomazone, pendimethalin, thiobencarb and quinclorac (PRE or POST); and/or supplemented with propanil or other POST herbicides. In Latin and South America, the Clearfield™ rice program is anchored on a combination imazapic, imazapyr, and imazamox with other herbicides. Variations of these programs are adopted in other world regions according to local climatic conditions and cropping systems.

In 2015, about 50% of rice areas in the Southern USA was planted with Clearfield rice™ (Sunny Bottoms, HorizonAg, pers. communication). In Arkansas, where about 50% of US rice is produced, about half of Clearfield hectares was planted with conventional cultivars, the other half was planted with hybrid rice in 2015 (Jarrod Hardke, Arkansas Rice Agronomist, pers. communication). In Brazil, 60% of irrigated rice fields were planted with Clearfield™ varieties 10 yr after the technology was released. In Italy, it is estimated that at least one-fourth of rice is now planted with Clearfield™ rice. New Clearfield™ cultivars and hybrid lines are actively being developed in the USA. The same is true with Argentina, Brazil, Italy, Malaysia, and Uruguay. The technology is effective. Among the cleanest rice fields in the USA are those planted with Clearfield™ rice and managed with a combination of herbicides with various modes of action. Similar could be said in other regions where the technology is used properly.

The greatest challenge with HR rice technology is the evolution of HR weedy rice via gene flow. No herbicide program can control all weeds all the time because of several mitigating factors (biotic or abiotic) – herbicide application parameters; weather; variability in weed emergence and growth stage; ecotypic diversity; seedbank size; farming practices; edaphic factors; and others. Therefore, some weedy rice are bound to escape some time, some place, and potentially hybridize with the HR crop. Such rare outcrosses are then selected by the herbicide (in this case, the imidazolinones), in succeeding seasons of planting Clearfield™ rice, and will produce progenies carrying the HR trait that will gradually dominate the soil seedbank. This is documented in all regions where Clearfield™ rice is grown; in some cases, after three cropping seasons. The agrichemical company marketing this technology (BASF) is cognizant of this ecological dynamics from the beginning. In Brazil, 90-100% of weedy rice from fields with history of Clearfield rice carried the resistance-conferring mutations of the acetolactate synthase (ALS) gene from HR cultivars planted (Roso *et al.* 2010). In Italy, about 50-60% of red rice sampled from Clearfield™ rice fields between 2010 and 2011were imazamox-resistant; all carried the $Ser_{653}Asn$ mutation from HR rice (Busconi *et al.* 2012; Scarabel *et al.* 2012). In Arkansas, USA, weedy rice outcrosses were detected in all fields sampled in 2010, which had been planted previously with Clearfield™ rice for various numbers of years (Burgos *et al.* 2014). The lesson is, once there are escapes and some of these synchronize in flowering with the HR rice and produce seed, it is the beginning of selection for HR weedy populations in succeeding seasons of HR rice. The proportion of HR progeny from escaped weedy rice will be low, as expected from a primarily self-pollinated plant (Shivrain *et al.* 2009), but this proportion increases with successive selection. In Arkansas, for example, weedy rice from Clearfield™ rice fields in 2010 had at least 20% of its progenies resistant to imazethapyr (Burgos *et al.* 2014).

To make the technology sustainable, a set of best management practices (Stewardship Guidelines) has been developed and strongly promoted with the technology by BASF in collaboration with partners in academia, government agencies, and private company. The guideline strongly touts integrated rice production practices (Anonymous 2011) that mirror the best management practices for weed resistance management (Norsworthy *et al.* 2014). It includes preplant cleanup, proper seed use, optimum planting practices, season-long diversified herbicide program, water management, sanitation of field surroundings, removal/control of escapes, postharvest clean-up, and crop rotation. The adoption of stewardship guidelines varies primary depending on economic constraints, technological support, and social and environmental constraints. Stewardship adoption is highest where these factors are favorable. For these reasons, stewardship adoption is expected to be highly variable in Asia and sustaining the technology will require great effort and strong collaboration across various sectors.

The rate of resistance evolution among weedy populations is expected to be faster in tropical regions where farmers usually plant five rice crops in two years. The absence of winter kill also allows faster increase in seedbank size. The residual activity of any soil-applied herbicides that may have some effect on weedy rice is also shorter in tropical than in temperate regions. Because rice is the staple food in most of Asia, and rice production is generally not enough to meet the demand in many countries, there is a great need for intensive rice production. Therefore, abiding by the crop rotation recommendations is very difficult. The most effective practice to reduce weedy rice infestation prior to the HR rice technology has been rotation of rice with other crops. In the southern USA, this is mostly rotation of rice with soybean which 80% of farmers practice (Burgos *et al.* 2008). In some regions in South America, rice is grown in rotation with pasture. Furthermore, rice is the main source of cash for rice farmers; the economic hurdle is most difficult to overcome. In the Americas and in Europe, many farmers grow Clearfield™ rice for more than two consecutive years. Therefore, a critical aspect of making this technology sustainable in Asia is prevention of seed production from escaped weedy rice and constant reduction of the soil seed bank by allowing weedy rice to germinate between rice seasons and controlling it with a combination of chemical and mechanical methods. Very tightly linked to this issue is volunteer rice. If the rotation is from Clearfield™ rice to conventional rice to break the cycle of ALS herbicide selection pressure (Scarabel *et al.* 2012), then volunteer HR rice can be a problem in the conventional rice season in addition to potential HR weedy rice outcrosses. The severity of the volunteer rice problem depends on the shattering trait of the HR cultivar and harvesting efficiency. In Arkansas, USA, the frequency of HR volunteer rice is higher following Clearfield™ hybrid than following a conventional Clearfield™ variety. In Asia, where seed loss from harvesting is high, volunteer HR rice problem will be high. As already mentioned also in the case of weedy rice, there is no killing frost that can naturally reduce the volunteer rice population. This problem will be significant in Asia. Not only will it increase the frequency of outcrossing and accelerate the evolution of HR weedy rice populations, high volunteer rice density will also reduce the yield and quality of the succeeding rice crop .

There is also the matter of spreading HR weedy rice by seed. HR weedy rice seed can be spread as contaminant of certified rice seed, 'brown-bagged' seed, farm equipment, or other agents. Seed laws are often lax in many countries, or non-existent in some. Italy, for example, allows 5 red rice seeds per 500 g commercial seed (Scarabel *et al.* 2012). If the farmer plants 50 kg seed ha^{-1}, he has planted also 500 red rice seeds/ ha. Saving seed (brown-bagging) is common in Asia and other regions. Sharing seed with relatives and neighbors is in the societal mindset. There is no quality control on saved seed besides what the farmer willingly invests toward that end. There is zero tolerance for weedy rice in certified seed in some countries including Brazil, Costa Rica, Philippines, Sri Lanka, and the USA. Experience tells us that zero tolerance has not been successfully implemented in all of these countries. Overcoming the seed quality problem takes rigorous education and outreach. Successful implementation of seed laws necessitates strong coordination and cooperation between government agencies for agriculture, private companies and agribusiness, academia, and farmer leaders. Keeping and monitoring high seed quality supply is a complex issue to tackle.

Corollary to the evolution of weedy rice populations from sustained selection pressure from ALS herbicides is the evolution of other ALS-resistant weed species in rice production areas. Since 2005, several ALS-resistant weeds other than weedy rice have been reported in countries producing Clearfield™ rice, including *Cyperus difformis*, *Cyperus esculentus*, *Cyperus iria*, *Echinochloa crus-galli*, *Echinochloa colona* and *Sagittaria montevidensis* (Heap 2015). Resistance to ALS inhibitors in the *Cyperus* and *Echinochloa* complex is co-evolving with resistance to ALS inhibitors in weedy rice. While resistance in weedy rice is almost exclusively due to gene flow, resistance in other species is due to selection of *de novo* resistance mechanisms.

The global challenge is to use HR technology sustainably. By current indicators, our collective effort is lagging behind weed evolution. It takes a global, concerted effort to catch up with weeds and, maybe, to stay ahead of it. Novel solutions and novel technologies (Lin et al. 2008; Gressel and Valverde 2009) that can be used to complement HR technology are gravely needed.

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Symposium – 3

Herbicide resistance: current status and future challenges globally

Herbicide resistance a global perspective

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Herbicide-resistant weeds combined with the decline in development of new herbicide sites of action present a serious challenge the long term viability of current weed control practices in global cropping systems. Multiple resistance (with combinations of both target site and non-target site mechanisms) in *Alopecurus, Amaranthus, Avena, Conyza, Echinochloa* and *Lolium* species are the biggest impending threat to sustained weed control.

Current status

There are currently 459 unique cases (species x site of action) of herbicide resistant weeds with approximately 11 new cases being reported every year. Herbicide resistant weeds have been reported in 86 crops in 66 countries and have evolved resistance to 22 of the 26 known herbicide sites of action (Heap 2015). North America remains the region with the greatest problems with herbicide-resistant weeds, followed by Western Europe, Asia, Australia, South America, and Eastern Europe (Fig. 1).

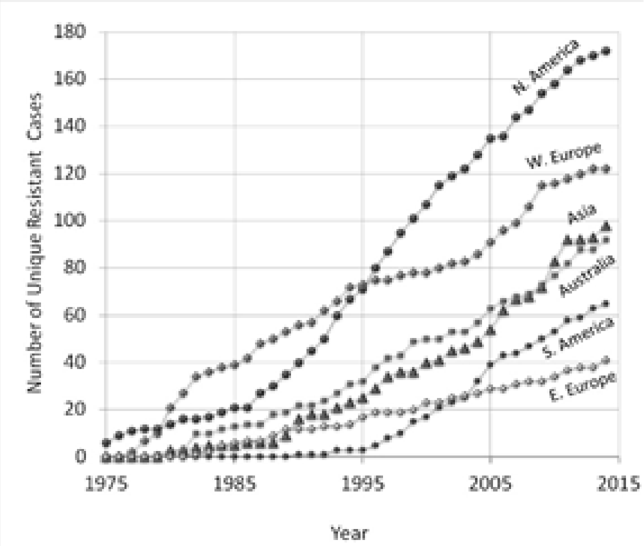

Fig. 1. Increase in unique herbicide resistant cases globally for several regions

Although much of the focus on herbicide-resistant weeds in North and South America is on glyphosate resistant weeds in Roundup Ready Crops, the greatest area and economic impact of herbicide-resistant weeds are to ALS inhibitor and ACCase inhibitor resistant weeds in cereal and rice production. In particular *Alopecurus, Apera, Avena, Bromus, Kochia, Lolium, Papaver, Phalaris, Raphanus, Setaria,* and *Stellaria* species in cereals and *Alisma, Cyperus, Echinocloa, Leptochloa, Lindernia, Sagittaria,* and *Schoenoplectus* species in rice.

Herbicide resistant crops

In the mid to late 1990s the introduction of Roundup Ready crops solved serious ALS and ACCase inhibitor resistance problems in soybean, corn, and cotton however the over reliance on glyphosate over a massive area eventually created it's own resistance problems. New herbicide resistant crops, such as synthetic auxin resistance in soybean, corn, and cotton will enable growers to control some glyphosate resistant weeds, but they themselves will eventually succumb to resistance quickly unless they are well managed.

CONCLUSIONS

To prolong the useful life of herbicides it will be necessary to adopt integrated weed management practices. Integrated weed management incorporates any economic combination of weed control strategies which may include preventative measures, monitoring, crop rotations, tillage, crop competition, harvest weed seed control, the use of different herbicide sites of action in rotation, sequence, and mixtures, herbicide resistant crops, biological controls, crop competition, nutrition, burning, and hand weeding. The key is to vary weed control strategies to destabilize evolution, because history has shown us that any consistent practice to control weeds year after year will result in directed evolution towards their survival.

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Herbicide resistance in weeds: Survey, characterization, and mechanisms

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Weeds have been in existence since before humans took up cultivation of plants for food, feed, fuel, and fiber. Before the advent of synthetic organic-based herbicides in the 1940s, weeds were controlled for thousands of years by mechanical, cultural, and biological means. 2,4-Dichorophenoxyacetic acid was the first herbicide to be used selectively. Since then, several herbicides belonging to different chemical classes and possessing diverse modes of action have been synthesized and commercialized around the world. Herbicides have vastly contributed to increasing world food production in an efficient, economic, and environmentally sustainable manner. However, repeated application(s) of the same herbicide or a different herbicide with similar mode of action on the same field, growing season after growing season, has contributed to the widespread occurrence of resistance to herbicides in several weed species. The goal of this paper is to present a systematic diagnostic approach towards the characterization of herbicide resistance in a given weed population with regards to profile (single, multiple, cross resistance), magnitude (fold level), mechanism, and related bio-physiological aspects.

The Weed Science Society of America (WSSA 1998) defines herbicide tolerance as "the inherent ability of a species to survive and reproduce after herbicide treatment." This implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant. Herbicide resistance is defined as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis" (WSSA 1998).

Diagnosing herbicide-resistant weeds as a first step in resistance management, and monitoring their nature, distribution, and abundance demands efficient and effective screening tests (Beckie *et al*. 2000). This can be achieved by crafting robust procedures for seed sampling, survey protocol and seed collection, seed processing and storage, germination, emergence and growth (sufficient number of representative plants), treatment conditions (discriminating dose, adjuvants, spray volume and parameters, water quality), experimental design, appropriate controls including wild type/ susceptible accessions, and biological parameters being measured.

Understanding the processes and means by which weeds withstand labeled herbicide treatments is an important step, as well, towards devising effective herbicide resistance management strategies. In general, five modes of herbicide resistance have been identified in weeds: (1) altered target site due to a mutation at the site of herbicide action resulting in complete or partial lack of inhibition; (2) metabolic deactivation, whereby the herbicide active ingredient is transformed to nonphytotoxic metabolites; (3) reduced absorption and/or translocation that results in restricted movement of lethal levels of herbicide to point/site of action; (4) sequestration/compartmentation by which a herbicide is immobilized away from the site of action in cell organelles such as vacuoles or cell walls; and (5) gene amplification/ over-expression of the target site with consequent dilution of the herbicide in relation to the target site. Current methodologies employed in herbicide resistance mechanisms research include: biochemical (enzyme kinetics and assays), physiological (photosynthesis, transpiration, respiration, chlorophyll biosynthesis, absorption and translocation using radioisotopes (Nandula and Vencill 2015)), and molecular (DNA and RNA-based) techniques. Newer mechanisms of herbicide resistance will most likely be discovered in the near future through the applications of 'omics' tools.

In conclusion, accurate and timely diagnosis of the nature and level of herbicide resistance in a weed population and knowledge about the inherent resistance mechanism(s) involved will greatly strengthen efforts towards devising sound herbicide resistant weed management strategies.

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Key herbicide-resistant weeds in the cereal production systems of US Great Plains

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The Great Plains of the United States comprise the major cereal production states in the country. In US, wheat (winter and spring wheat) was grown in 45 million acres in 2014, with a total production of 55 M metric tons. Wheat after summer chemical fallow (W-F) dominates > 90% of the dryland cropping systems of the northern Great Plains, where soil moisture (< 30cm of average annual precipitation) is often the limiting factor for continuous cropping. In the central Great Plains, wheat-corn/grain sorghum- fallow (W-C/G-F) is a common dryland rotation. Over-reliance on herbicides for weed control in these no-till cropping systems has resulted in weed-species shifts and evolution of herbicide-resistant weeds.

METHODOLOGY

"The International Survey of Herbicide Resistant Weeds website is a source for documenting and monitoring the evolution of herbicide-resistant weeds and assessing their impacts on agricultural production systems" (Heap 2015).Globally, the maximum number of herbicide-resistant weed species has been reported in wheat (Heap 2015). This paper documents the occurrence, resistance mechanisms, and management of key herbicide-resistant weeds in the US Great Plains cereal production systems.

RESULTS

Glyphosate (burndown), ACCase-inhibitors, ALS-inhibitors, and synthetic auxins are the most commonly used herbicide chemistries in cereal production. Wild oat resistant to ACCase-inhibitors is widespread across the US Great Plains wheat belt. Wild oat resistance to ALS-inhibitors has been documented. Recently, wild oat strains with multiple resistance to ACCase-inhibitors, ALS-inhibitors, and difenzoquat have been reported in Montana, USA. Green foxtail resistance to ACCase-inhibitors has also been reported in this region. Prickly lettuce biotypes resistant to ALS-inhibitors and synthetic auxins (2,4-D, dicamba, and MCPA) are known to occur in wheat fields. Russian thistle has developed resistance to ALS-inhibitors used in wheat. The recent evolution of glyphosate-resistant kochiain ten states and presence of auxinic (dicamba and fluroxypyr)- and ALS-inhibitor-resistant kochia is a potential threat to cereal production in the US Great Plains (Heap 2015). Kochia with multiple resistance to glyphosate, dicamba and ALS-inhibitors is a challenge for the wheat producers. *EPSPS* gene amplification and *ALS*-gene mutation confer resistance to glyphosate and ALS-inhibitors in kochia (Kumar *et al.* 2015). Glyphosate-resistant kochia seed bank in W-F rotation should be effectively managed with alternative, effective herbicides available in the wheat crop. It is crucial to adopt a "zero tolerance approach" to kochia seed production in crops (corn, wheat/barley: more effective alternative modes of action available) preceding chemical fallow. Diversifying crop rotation with inclusion of pulse and oilseed in no-till W-F rotation would add diversity in weed management and allow use of soil-residual herbicides to reduce selection pressure from repeated glyphosate applications in fallow/wheat stubble. Targeted tillage would be a component of herbicide resistance management program.

CONCLUSION

Herbicide resistance is an increasing threat to the sustainability of cereal production systems in the US Great Plains. An integrated weed management (IWM) approach needs to be implemented.

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Herbicide-resistant weeds in the northern grain region of Australia

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The northern grain region reports the maximum number of glyphosate-resistant weeds in Australia. Other than glyphosate, many weeds evolved resistance to ALS and ACCase inhibiting herbicides. The conservation tillage practices, intensive use of herbicides, introduction of glyphosate-tolerant crops, and highly diverse weed populations due to soil and weather characteristics are the major factors contributing to the rapid rate of herbicide resistance evolution in this region. Unlike the other regions in Australia, the tropical and subtropical climate with rainfall distributed during summer and winter facilitates abundance and diversity in weed populations. However, cropping in this region is also highly diversified due to weather and soil characteristics. This diversity allows to integrate different weed management tactics by exploiting weed ecology and competition, and ensures diversity in crop choices, non-chemical tactics, and herbicide options.

Herbicide-resistant weeds in the northern region

Maximum number of glyphosate–resistant weeds in Australia are reported from the northern region (Table 1) (Preston 2015). So far, *Loliumrigidum* Gaud., *Chloris truncate* R.Br., *Conyza bonariensis* (L.) Cronq., *Echinochloa colona* (L.) Link, *Sonchus oleraceusL.* and *Urochloa panicoides* P. Beauv. have evolved resistance to glyphosate (Cook *et al.* 2014).

Table 1. Weeds and their populations evolved resistance to glyphosate in the northern grain region

Weed species	Number of populations
Echinochloa colona	91
Lolium rigidum	67
Conyza bonariensis	30
Sonchus oleraceus	5
Urochloa panicoides	4
Chloris truncata	4

Another major resistance issue is the high number of weeds evolving resistance to ALS inhibiting herbicides. In the northern region, chlorsulfuron (an ALS inhibiting herbicide) has been used predominantly in winter cereal systems to control many grass and broadleaved weeds. The rapid resistance development against ALS herbicides is attributed to the high herbicide selection pressure from these herbicides (Adkins *et al.* 1997; GRDC 2012). The first resistant cases in this region in *S. oleraceus* and *Rapistrum rugosum* (L.) All were reported by Adkins *et al.* (1997). Later on, *L. rigidum* and *Raphanus raphanistrum* L. populations evolved resistance to chlorsulfuron. *Avena* spp. (wild oats)resistance against ALS herbicide mesosulfuron was also reported from this region (GRDC 2012).

In a survey in 2012-13, herbicide resistance to the auxinic herbicide 2, 4-D was tested in *C. Bonariensis* and *S. oleraceus*. The screening confirmed 2,4-D resistance in *S. Oleraceas* (Cock et al. 2014). Among the grassy weeds, *Avena* spp., *E. colona*, and *Phalaris paradoxa* have evolved resistance to ACCase inhibiting herbicides. In addition, *E. colona* and *U. panicoides* have evolved resistance to the triazine group of herbicides (GRDC 2012).

Reasons for resistance development

With the adoption of conservation tillage, many small-seeded weeds with abundant seed production have evolved as dominant weeds in many agro-ecosystems around the world. In the northern region, the dominant weeds are *Chloris virgata* Sw., *C. truncata*, *C. bonariensis*, *E. colona*, *L. rigidum*, and *S. oleraceus*. Unlike the other regions in Australia, the rainfall during winter and summer seasons facilitates high diversity and abundance in weed growth throughout the year. The weeds in summer fallows, if unattended, can be a problem due to ideal growing conditions because of profuse summer rains. In the northern region, glyphosate is widely used in weed control in fallows and uncropped areas due to the environmental benefits, efficacy, and reduced cost. The high selection pressure imposed by glyphosate led to a maximum number of resistance cases developing against glyphosate (Preston 2015). In addition, the introduction of herbicide-tolerant crops further increases glyphosate selection pressure in this region. As an example, glyphosate-tolerant weeds are getting prevalence in cotton tracts due to the adoption of the Roundup Ready Flex® technology (Werth *et al.* 2013). The resistance to the ALS inhibiting herbicide chlorsulfuron is attributed to the risks associated with this herbicide group, as herbicide resistance evolution can be faster compared to glyphosate. In addition, the lack of diversity in weed management is also a major reason for the rapid evolution of resistance against this herbicide group.

Weed ecology and reproductive biology can favour some weeds to be dominant species. For example, surface germination, high reproductive potential, and wind seed dispersal are favouring *C. bonariensis* to evolve herbicide resistance at a rapid pace (Walker *et al.* 2011). Similarly, wind dispersal and surface germination favours *S. oleraceus* as the dominant weed under conservation tillage. *E. colona*, a major summer fallow weed, is favoured by summer dominant rainfall. Under ideal conditions, *E. colona* can produce around 42,000 seeds (Widderick et al. 2013). More than 98% of glyphosate resistance cases in *E. colona* is reported from chemical fallows (Preston 2015). *L. rigidum* is the major winter season weed in this region; abundant seed production and cross pollination are two major attributes that help this weed to thrive the herbicide selection pressure.

Management options for herbicide resistance

There are challenges and opportunities for weed management in the northern region. The weed flora in the northern region is quite diverse due to the rainfall pattern and soil characteristics. There is abundant weed growth throughout the year due to winter and summer rainfall (Cook *et al.* 2014). Therefore, potential exists for each and every weed to be a dominant weed under unscientific weed management. The uncultivated and summer fallows can act as breeding ground for many weeds. The reliance on glyphosate for fallow management has led to the maximum number of glyphosate-resistant weeds (Preston 2015). However, the cropping is also diversified in the northern regions and there exist the feasibility to rotate different crops during winter and summer. Therefore, diversifying weed management through crop rotations and including herbicide-tolerant crops is highly feasible in this region. In addition, crop competition can be exploited to suppress weeds effectively by the selection of crop variety, seeding rate, row spacing, and time of planting. The cropping options in both winter and summer would diversify tillage. In addition, feasibility exists for inter row cultivation (Holland and McNamara 1982) and occasional strategic tillage as these practices would disturb dominant weed flora under conservation tillage (Cheam and Lee 2005). Wide row spacing and controlled trafficking would enhance the feasibility for integrating both chemical and non-chemical tactics. Harvest weed seed control is quite successful in Western Australia; however, more research or modification of machinery may be required as the performance can vary on tiny weed seeds like *C. bonariensis* and *S. oleraceus*.

Opportunities exist in diversifying herbicide management through herbicide rotations, including residual herbicides, practising the double knock tactic (sequential application glyphosate followed by paraquat), and by applying combination of herbicides from different modes of action. The weed management in fallows and non-cropped areas are a major concern in the northern region. The cost of herbicides is the major factor that prevents growers form trying herbicides other than glyphosate for fallow weed management. Recently, the WeedSeeker® sensor technology is gaining acceptance in Australian agriculture (GRDC 2014). This technology has advantages because less area in a paddock needs to be covered by a herbicide. Therefore, growers can rely on costly herbicides other than glyphosate in fallow weed management and that may reduce the selection pressure from glyphosate (GRDC 2014).

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Management of multiple herbicide resistant in *Phalaris minor* in India

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Phalaris minor Retz. (Littleseed canary grass), the most ubiquitous weed of wheat in North India has become the most difficult weed denting wheat productivity. It has evolved multiple resistance to the recommended herbicides, isoproturon (PSII), diclofop-methyl, fenoxaprop-P-ethyl, clodinafop-propargyl, pinoxaden (ACCase), sulfosulfuron and premix of mesosulfuron+iodosulfuron (ALS inhibitors) mediated by enhanced metabolism and target site mutations. Growth stage dependent control with POE metribuzin and inconsistent results with PRE pendimethalin (soil tilth and moisture), further intensified the woes of Indian farmers grappling with resistant populations of *P. minor*. Limited choice of new molecules of altogether new site of action, require an exigent strategy for the management of resistant populations as farmers have to spray repeatedly two or three applications either alone or in combination of the three chemical groups of herbicides resulting in higher cost of weed control or reduced efficacy. Knowledge of *P. minor* biology revealed loss of viability after two year under field conditions and 6-7 years under lab conditions; however, huge population pressure in resistant fields suggests migration of seed from other sources. Similarly, continuous zero tillage operations for wheat sowing should exhaust the soil seed bank to reduce *P. minor* seed rain over the years creating weed free situations, but that did not happen practically as resistance also occurred in zero tillage system and at present there are no concluding studies about resistant *P. minor* seed movement from other sources.

Herbicides alone are no panacea to manage resistant weeds over the years, but effective weed management without herbicides is also not tenable, as herbicides are pivotal for any future weed management strategy. Integrated weed management using intelligent agronomic practices are recommended in combinations, and are effective with herbicides but need new substitutions to beat the weeds in their swiftness to acquire resistance to the same strategy used repeatedly.

Studies conducted at CCS Haryana Agricultural University, Hisar using the seed collected from resistance affected fields revealed that most of these populations are resistant to the existing herbicides, without any distinct pattern to herbicides of different chemical classes. Under these situations, it is very difficult for the farmer to select the most appropriate herbicide for the management of resistant populations without advance knowledge of effective herbicide. A rapid resistance detection test could aid farmers to opt for the most effective herbicide. Among the new herbicides pyroxasulfone (Protox inhibitor) PRE is effective against *P. minor*, but need a mixture partner for increased spectrum of weed kill. Though PRE herbicides provide inconsistent results due to soil preparation (stubbles) and soil moisture, but they have been found to lower weed pressure significantly resulting in less competition with wheat in early growth stages and sets the stage for effective control for sequential herbicides to take care of residuals and new flushes emerging after first or second irrigations.

Several field studies carried out under resistance affected farmer's fields using herbicides mixtures and their sequential application provided promising results. Pendimethalin or pyroxasulfone PRE followed by POE pinoxaden, sulfosulfuron or Atlantis (mesosulfuron + iodosulfuron) has been found effective against resistant *P. minor*; however, neither pendimethalin nor pyroxasulfone alone could provide satisfactory control, but a mixture of both was effective against *P. minor* and other weeds. In the absence of PRE herbicide treatment; sequential application of sulfosulfuron 20-25 DAS (before first irrigation) followed by pinoxaden 40-45 DAS can be used for a short time to manage the resistant populations; however clodinafop followed by pinoxaden failed to control resistant populations. POE tank mix application of clodinafop, pinoxaden, Atlantis or sulfosulfuron with metribuzin significantly improved the control than their alone applications; but greater propensity of *P. minor* for enhanced metabolism of PSII inhibitors, metribuzin may not be very advisable in the long run. Other potential mixtures include pendimethalin + metribuzin, pyroxasulfone/flufenacet/mesosulfuron + metribuzin, flufenacet + pyroxasulfone/pendimethalin/sulfosulfuron/ mesosulfuron and mesosulfuron+ metribuzin; however, tank mix of clodinafop with sulfosulfuron was found less effective. Metribuzin has been found to provide good control, but its alone application caused crop injury particularly under higher moisture conditions and some varieties are more sensitive to metribuzin; its PRE application was less effective. Delayed application of metribuzin was less effective and required higher dose for the same level of control. Regeneration and emergence of new flush of *P. minor* has been observed with all herbicides and need a course correction to have a second application of herbicides that is still not used in India.

CONCLUSION

An integrated approach adopting appropriate cultivation methods, sowing time, seed rate, competitive varieties, crop rotation, mixed farming, choice of herbicide, surfactants, synergistic mixture or sequential partner, their application rates, timings, application methods, nozzles types, water volume, herbicide rotations, time of fertilizer and irrigation, straw management, scouting for escapes and weed flora shift, mechanical control methods, seed contamination/ movement, applying the knowledge of weed biology and biotechnology tools are needed in the management strategy of multiple herbicide resistant *P. minor*.

Multiple herbicide resistance in key broadleaf weeds in US Great Plains

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Evolution of weed resistance to herbicides complicates weed management and threatens sustainable agricultural production and soil and water conservation gains achieved during the past two decades. Several major weeds have evolved resistance to two or more classes of herbicides (Heap 2015). Kochia (*Kochia scoparia* Schrad.) and Palmer amaranth (*Amaranthuspalmeri*S. Watson) are two such broadleaf weeds of great economic importance in the North American Great Plains (Ward *et al.* 2013; Godar *et al.* 2015). We tested *kochia* and *Palmer amaranth* populations for multiple site of action resistance.

METHODOLOGY

Seed plants from a single population of kochia and two populations of *Palmer amaranth* grown in a greenhouse were sprayed separately with field rates of atrazine, chlorsulfuron, dicamba, glyphosate or mesotrione. Plant response (dry weight) or survival was assessed 4 weeks after treatment compared to untreated controls. Treatments were replicated four or more times and experiments were repeated. Genomic DNA was isolated and gene specific primers were used to amplify psbA (encodes D1 protein of PSII), acetolactate synthase (ALS), and 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) genes, the target sites of atrazine, chlorsulfuron and glyphosate, respectively. The PCR amplified fragments were sequenced. Furthermore, the EPSPS gene copy number relative to ALS (reference gene) was also determined using quantitative PCR.

RESULTS

Ratio of R: S plants to individual herbicides varied from low to high frequency of R plants within populations. Resistance to four groups of herbicides (PSII, group C1/5; ALS, group B/2; synthetic auxin; group O/4; and EPSPS inhibitors, group G/9) was confirmed in a single kochia population (Varanasi *et al.* 2015) and resistance to three herbicide modes of action were confirmed in two Palmer amaranth populations. Both *Palmer amaranth* populations were resistant to atrazine (PSII, group C1/5) and chlorsulfuron (group B/2); one population also was resistant to mesotrione (group F2/27) and the other population also was resistant to glyphosate (group G/9). In *Kochia*, resistance to atrazine and chlorsulfuron was found to have evolved as a result of point mutation in psbA and ALS genes, respectively. On the other hand glyphosate resistance in *Kochia* is due to *EPSPS* gene amplification. Experiments are in progress to determine the mechanism of multiple herbicide resistance in Palmer amaranth.

CONCLUSIONS

A least one population of kochia in Kansas has evolved resistance to four herbicide modes of action and at least two Palmer amaranth populations has evolved resistance to three herbicide modes of action.

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Molecular cytogenetic mechanism(s) of *EPSPS* gene amplification in glyphosate-resistant weeds

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Extensive, often exclusive, use of glyphosate in crop production has resulted in evolved glyphosate resistance in several weed species globally. In the US glyphosate-resistant kochia (*Kochia scoparia*), waterhemp (*Amaranthus rudis*) and Palmer amaranth (*Amaranthus palmeri*), are serious threat to sustained agricultural productivity. These weeds evolved resistance to glyphosate by gene amplification of 5-enolpyruvyl shikimate 3-phosphate synthase (*EPSPS*), the target-site of glyphosate. In this research we investigated the molecular cytogenetic analysis of *EPSPS* amplification in the above weeds to help understand the mechanism of *EPSPS* gene amplification and the evolution of glyphosate resistance.

METHODOLOGY

Quantitative RT-PCR on cDNA was used to measure the relative expression of *EPSPS* gene. The genomic organization of the amplified *EPSPS* copies was determined using fluorescent in situ hybridization (FISH) or extended DNA fiber (Fiber FISH). Somatic chromosome preparations, direct probe labeling (by nick translation), and the FISH procedure on glyphosate-resistant and –susceptible plants were performed as described previously (Kato *et al*. 2006) with minor modifications.

RESULTS

The results of qRT-PCR on cDNA revealed a positive correlation between *EPSPS* copies and gene expression in all the species. FISH results displayed a single and prominent hybridization site of the *EPSPS* gene localized on the distal end of one pair of homologous chromosomes compared to a faint hybridization site in susceptible samples of kochia. Fiber FISH displayed ten copies of the *EPSPS* gene, arranged in tandem configuration in kochia. Whereas, FISH analysis of common waterhemp plants with 2 to 10 *EPSPS* copies displayed a brighter hybridization signal on one pair of homologuous chromosomes likely near the centromeric region compared to a faint hybridization site in susceptible plants. Interestingly, in some Common waterhemp plants with >10 *EPSPS* copies, an additional chromosome with *EPSPS* hybridization signals all around the chromosome was found. On the other hand, FISH analysis of glyphosate-resistant Palmer amaranth revealed distribution of *EPSPS* copies throughout the genome as reported previously by Gaines *et al.* (2010).

CONCLUSIONS

These results of this research suggest that mechanisms of *EPSPS* gene amplification in glyphosate-resistant weeds appeared to be species specific. The *EPSPS* gene amplification may have occurred via unequal recombination in kochia (Jugulam *et al*. 2014) or possibly mediated by transposons in Palmer amaranth (Gaines *et al*. 2013). Experiments are in progress to determine the mechanisms of amplification in these species.

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Herbicide-resistant weeds: management strategies and upcoming technologies

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Herbicides have contributed to substantial increase in crop yields over the past five decades. Herbicide use increased more than ten-fold between 1960 and 1981 as more U.S. farmers began to treat their fields with these chemicals. By 1980, more than 90-99% of U.S. corn, cotton, and soybean area was treated with herbicides as compared to 5-10% of area planted in 1952. Over reliance on herbicides for weed control has led to rapid evolution of herbicide-resistant (HR) weeds. As of 2015, globally, 245 weed species (103 monocots and 142 dicots) have evolved resistance to 157 herbicides representing 22 of the 25 known herbicide sites of action in 86 crops in 66 countries (Heap 2015). Herbicide-resistant crops (HRCs), mainly glyphosate- and glufosinate-resistant soybean, corn, cotton, and canola were commercialized in the mid-1990s. The consistent weed control and economic benefits of HRCs encouraged the farmers to plant more area with HRCs each year in countries where adopted. In the US, 94% of soybean, 91% of cotton, and 89% of corn area was planted with glyphosate-resistant (GR) cultivars in 2014. Globally, 82% of soybean, 68% of cotton, and 30% of corn area was planted with GR cultivars in 2014. The remarkable success of GR crops has increased glyphosate use, consequently, increasing selection pressure that resulted in widespread evolution of GR weeds. By 2015, globally, 32 weeds have developed resistance to glyphosate (Heap 2015).

Herbicides are still essential for weed management in modern cropping systems. Increased awareness of herbicide resistance and adoption of diversified weed control tactics by farmers is critical to manage HR weeds. HR weed management must include use of cultural (competitive cultivars, plant densities, row spacing, crop rotation, winter crops in rotation, cover crops), mechanical (tillage before planting, cultivation, hand hoeing), chemical (herbicide full-labelled rate, tank mixtures at the label rate, sequences, application timing, herbicide rotation with different modes of action), and biological tactics available for effective weed control (Reddy and Nandula 2012). Other management practices include use of weed-free crop seed, keeping fields weed-free, preventing within field and between fields movement of weed seed, and understanding the biology of the weeds and use of diversified weed management approaches to prevent weed seed production and depletion of weed seed in soil seedbank. The severity of HR weed problem has also renewed efforts to discover new technologies. One technology will be a new generation of crops with resistance to glyphosate, glufosinate and other existing herbicides. Currently, Monsanto, Dow, Bayer, Syngenta and BASF are developing new stacked-trait crops in combination with glyphosate resistance. They are glyphosate, glufosinate (soybean, corn, cotton); glyphosate, ALS inhibitors (soybean, corn); glyphosate, glufosinate, 2,4-D (soybean, cotton); glyphosate, glufosinate, dicamba (soybean, corn, cotton); glyphosate, glufosinate, HPPD inhibitors (soybean and cotton); glyphosate, glufosinate, 2,4-D, ACCase inhibitors (corn); and glufosinate, dicamba (wheat).These stacked-trait crops will provide new options with existing herbicides, but will not be the total weed management solution because several weeds have already evolved resistance to these herbicides.

Another technology in the early stages of development that has potential to combat HR weeds is use of RNA interference (RNAi) technology (BioDirect™ by Monsanto). The use of RNAi involves the topical application of double-stranded RNA (dsRNA) to interfere with the expression of herbicide resistance genes in weeds. The field experiments have demonstrated that BioDirect™, when combined with herbicide, can reverse resistance. The technology has also been demonstrated with weeds resistant to ALS-, HPPD- and PPO-inhibiting herbicides. RNAi is a revolutionary technology for resistant weed management, but is still years away from commercialization. While no new herbicides are on the horizon, in the near future, the HR management strategies must utilize an array of tools to disrupt HR weeds from evolving and spreading, with the ultimate goal of not allowing any weeds to survive and set seed.

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Modeling the evolution of herbicide resistance in weeds: current knowledge and future directions

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Simulation models are being used to gain a deeper understanding of herbicide resistance evolution and devise effective management strategies (Neve *et al.* 2011). A prime benefit is that models allow for the comparison of various management options and evaluate the relative benefits of different management combinations in reducing the risk of resistance (Jasieniuk *et al.* 1996). For instance, Bagavathiannan *et al.* (2013) used a model to compare the relative benefits of altered planting dates, cultivation, crop/trait rotations, and herbicide rotations in proactive resistance management. Thus, models can serve as excellent decision-support tools for making informed management decisions.

Current knowledge

The evolution of herbicide resistance is influenced by three key factors: (1) factors related to the ecology and biology of the weed species, (2) genetic factors governing the rate of resistance evolution, and (3) management factors. Therefore, models that simulate herbicide resistance evolution comprise of three integral components - ecology and biology, population genetics, and management. The processes on ecology and biology is usually represented by a demographic sub-model, which accounts for initial seedbank size, annual germination proportion, seedling recruitment pattern, density-dependent survival and fecundity, post-dispersal seed loss, and seed immigration/emigration. The genetic processes include initial frequency of resistance alleles, mode of inheritance of resistance, mating system, dominance, and fitness. Management is a critical factor determining resistance evolution, particularly the combinations of management options used and efficacies of different options.

In a pioneering research, Gressel and Segel (1978) used a simple population model in an attempt to identify important factors that influence the evolution of herbicide resistance. Since then, several resistance simulation models have been developed for specific situations (Maxwell *et al.* 1990). Model sensitivity analysis is used to identify the key parameters that influence model dynamics. Some notable ones for which the models were found to be highly sensitive include initial seedbank density, initial frequency of resistance alleles, proportion of seedling recruitment, post-dispersal seed loss, and annual seedbank loss (Neve *et al.* 2011; Bagavathiannan *et al.* 2013). Diggle and Neve (2001) outlined the specifics of herbicide resistance simulation modeling and the applications and limitations of various methodologies used in model development. The vast majority of the existing models focus on single major-gene based resistance.

Future directions

The single major-gene based models have been highly valuable, but given the increasing cases of multiple resistance (resistance to more than one herbicide mechanism of action) and polygenic resistance (resistance endowed by several minor-effect genes), there is a need for more focus on these aspects. Diggle *et al.* (2003) predicted the risk of multiple herbicide resistance evolution conferred by two discrete, unlinked nuclear genes. Bagavathiannan *et al.* (2014) used a model to simulate simultaneous evolution of resistance to two herbicide mechanisms of action in barnyardgrass in US rice production. Future resistance simulation models will increasingly focus on multiple herbicide resistance. Polygenic herbicide resistance is an emerging issue and attempts have been made to better understand this phenomenon using simulation models. Renton *et al.* (2009) developed the PERTH (Polygenic Evolution of Resistance to Herbicides) model for demonstrating the polygenic basis of resistance evolution in annual ryegrass (*Lolium rigidum* Gaud.) under low herbicide doses. There are several challenges with modeling polygenic resistance evolution and more efforts are necessary to adequately model and understand the evolutionary dynamics of polygenic resistance in weeds.

Most models developed so far predict resistance under homogeneous environments. However, production fields are typically heterogeneous and resistance evolution and spread largely occurs at spatially heterogeneous patterns. A small number of models have been developed by accounting for the movement of propagules in a heterogeneous spatial scale (Richter *et al.* 2002). Inclusion of spatial heterogeneity will be valuable in future models. Further, most of the existing resistance simulation models are deterministic (do not account for environmental and demographic stochasticity) and inclusion of stochasticity will greatly improve the reliability of model predictions.

CONCLUSION

Simulation models have been instrumental in understanding the evolutionary dynamics of herbicide resistance in weeds and making informed management decisions for preventing/delaying resistance. Continued improvements in model development and analysis will be critical to address the complex interactions involved in herbicide resistance evolution.

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Effect of elevated temperature on glyphosate and dicamba efficacy in broadleaf weeds

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Herbicide efficacy is known to be influenced by environmental factors, including temperature. Many studies have reported decreased POST herbicide efficacy at higher temperatures, but some have reported the opposite trend (Johnson and Young 2002; Waltz *et al.* 2004). Kochia (*Kochia scoparia)* and Palmer amaranth (*Amaranthus palmeri*) are economically important broadleaf weeds in United States. Dicamba (auxinic herbicide) and glyphosate (amino acid biosynthesis inhibitor) offer effective herbicide options to control these weeds. In this study, the effect of growth temperature on efficacy of dicamba and glyphosate in kochia and Palmer amaranth was investigated.

METHODOLOGY

Dicamba- and glyphosate- susceptible kochia and Palmer amaranth were grown in growth chambers maintained at different temperatures (day/night, °C): low (LT), 17.5/7.5; optimum (OT), 25.0/15.0; and high (HT), 32.5/22.5. When plants reached 8-10 cm tall, they were treated with 0, 1/32, 1/16, 1/8, 1/4, 1/2, 1X rates of dicamba (where X is 560 g ae/ha) or glyphosate (where X is 840 g ae/ha). Visual injury, fresh and dry biomass were recorded 4 weeks after treatment. Each treatment had 4-6 replications and experiments were repeated. Furthermore, to determine the physiological basis of reduced dicamba or glyphosate efficacy under high temperature, dicamba or glyphosate uptake and translocation experiments were conducted using 6-8 cm tall kochia plants grown under above temperatures. Ten µL of dicamba (3.0 g ae/L) or glyphosate (4.5 g ae/L) containing 20,000 dpm/µL of 14C radioactivity was applied on two newly matured leaves. At 24, 48 and 72 hours after treatment plants were harvested and the radioactivity was estimated.

RESULTS

Results of this research suggests that in both kochia and Palmer amaranth the efficacy of glyphosate or dicamba was increased to control plants grown under low than high temperatures. More importantly, the increased efficacy of these herbicides under LT was attributed to increased translocation of dicamba or absorption of glyphosate in kochia. In a recent study we concluded that Palmer amaranth was more sensitive to mesotrione (a carotenoid biosynthesis inhibitor) at cooler temperatures due to rapid metabolism of mesotrione and increased expression of target gene (Godar *et al.* 2015).

CONCLUSIONS

In conclusion, to improve the efficacy of dicamba or glyphosate for kochia or Palmer amaranth control, these herbicides can be applied early in the season or when temperatures are cooler.

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Resistance evolution among *Echinochloa* species in the Southern USA

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At least 10 species of the *Echinochloa* genus are found in the USA. This genus is most commonly, and collectively, called barnyardgrass although the name also specifically refers to the *E. crus-galli* species. Some species of this genus, including *E. crus-galli* and *E. colona* (jungle rice), are major weed problems in agronomic and horticultural crops in the USA and worldwide. Because this genus generally thrives in wetlands and/or flooded ecosystems, some species proliferate and become weeds in rice production ecosystems. The barnyardgrass and junglerice complex is the most serious grass weed in the southern US rice belt.

The most predominant species in the southern USA is junglerice. Specifically in Arkansas, junglerice occurs in about 65% of the rice production fields, while barnyardgrass is present in about 25%, of rice fields surveyed between 2012 and 2014. *E. muricata* (rough barnyardgrass) is found in 30% of the rice fields where it occurs mostly in the peripheries of rice paddies, with a few cases inside the paddy. Thus, in 30% of the fields, *Echinochloa* infestation is not limited to a single species but various combinations of these species. Only 35% of fields are infested with junglerice alone and 7% are infested with barnyardgrass alone. Notwithstanding the relative species abundance, *Echinochloa* species have co-evolved complex resistance patterns to various herbicides. In rice production, the stacking of resistance traits in *Echinochloa* is facilitated by successive selection with herbicides of different modes of action. This is demonstrated by the resistance evolution among *Echinochloa* populations in Arkansas rice fields. First was resistance to propanil in 1989, following three decades of widespread use. Quinclorac was introduced in 1992 to mitigate resistance to propanil; in 1999, a population with multiple resistance to propanil and quinclorac was confirmed. This problem was fixed (temporarily) by the introduction of clomazone for grass weed control in rice in 2000; clomazone-resistant barnyardgrass was detected in 2006.

The commercialization of Clearfield® rice in 2002 allowed for the increased use of ALS inhibitors for *Echinochloa* control, in addition to the main purpose of controlling weedy rice (*Oryza sativa* L.). In 2008, the first ALS-resistant barnyardgrass in the southern US was confirmed. Selective grass herbicides (cyhalofop and fenoxaprop) are used also in rice production. Resistance to these herbicides has been detected more recently. Thus, across 2012 to 2014, resistance to propanil among *Echinochloa* spp. occurs in about 50% of sampled rice fields in Arkansas, resistance to quinclorac in 40%, and resistance to imazethapyr and cyhalofop in about 10% of fields, respectively. Different patterns of multiple resistance among populations and among *Echinochloa* species are observed. Arkansas populations follow similar trends as the rest of the southern US with widespread resistance to propanil, followed by resistance to quinclorac and ALS inhibitors (primarily imidazolinones). Resistance to 3 or 4 modes of action in one population have been reported. Herbicide-resistant *Echinochloa* species have been managed thus far with diversified herbicide programs and crop rotations when possible. Some new herbicide chemistries and technologies are on the horizon for rice production. These could stave off resistance evolution for some time, but will need broader integration of agronomic practices to be sustainable.

Best management practices for mitigating herbicide resistance: A review

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The best management practices (BMPs) for herbicide resistance (HR) management in weeds are established on the concept of diversity. "Mitigating HR will depend on reducing selection pressure by diversification of weed control tactics, reducing the spread of resistance alleles via pollen or seed, and preventing weed seedbank additions" (Norsworthy *et al.* 2012). Farmers are reluctant to change their weed control practices or adopt proactive HR management programs because of their interest in short-term economic returns and lack of awareness on evaluating the economic risks associated with HR weeds until resistance has evolved in their production fields (Beckie 2006). Herbicides will continue to be the dominant weed-management tool globally; however, farmers should not expect many new sites of action to be commercialized in the near future.

In this review, BMPs to effectively delay or manage HR weeds are summarized (Beckie 2006; Norsworthy *et al.* 2012). Adoption of these BMPs by growers and agricultural professionals will aid in mitigating the evolution, spread, and economic impact of HR weeds.

1. *Understand the weed biology*. Make informed weed-management decisions based on understanding of the weed seed germination, dormancy, persistence in the soil seed bank, seedling emergence pattern, reproductive biology and phenology, and mode of seed dispersal. Escaped HR plants should be eliminated before flowering. Weed seed bank replenishment at or after harvest should be prevented. Preventing the influx of HR weeds into the field from field borders or fence lines is critical.
2. *Integrate cultural and mechanical weed management practices*. Some of these approaches include:
   a. Plant crops in weed-free fields.
   b. Use high crop-seeding rates, narrow-row spacing, optimum fertilization, and strategic irrigation methods to enhance crop competition against weeds.
   c. Diverse crop rotations inherently include the use of multiple weed management tactics.
   d. Use mechanical (tillage, in-row cultivation, mowing) or biological (cover crops and synthetic mulch) management practices where and when appropriate.
3. *Add herbicide diversity*. The following recommendations can help achieve this goal:
   a. Timely scouting is essential for early detection of HR weeds.
   b. Apply herbicides at full labelled rates and adjuvants.
   c. Target herbicide applications at the recommended weed sizes.
   d. Rotate herbicides with different modes of action over multiple growing seasons.
   e. Use herbicide mixture(s) (tank-mixed or sequential applications) that include multiple, effective modes of action, which can target the same weed with similar efficacy and have similar persistence, degrade differently, and may be synergistic in their activity on weeds.
   f. Incorporate PRE soil-residual herbicides instead of a total POST weed control program.
   g. Rotate crops with multiple HR traits or HR with non-HR traits.
   h. Adopt site-specific herbicide application using GIS maps and sensor-based precision weed control technology for patch management.
4. Use decision-support systems, for example RIM (resistance and integrated management) model developed in Australia as an IWM-decision-making tool.

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Herbicide-resistance in weeds and crops: interactions and impact on farming sustainability

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Herbicide-resistant weeds are spread now all over the world in annual and perennial crops mainly due to misuse of herbicides. Weeds resistant to triazines, ALS, ACCase and PPO inhibiting herbicides and glyphosate have evolved in all continents threatening the sustainability of crop production. Over reliance on chemical control, repeated use in perennial crops, lack of crop and herbicide rotations combined with reduce tillage resulted in evolution of numerous weed species resistant virtually to most herbicidal mode of actions (MOA). Lack of a novel MOA of herbicides aggravates the situation. Altered target site (TS)' caused by point mutation(s) in the binding site sequence and a non-target site (NTS) mechanisms may render weeds resistant to herbicides. The pattern of herbicide-resistant weeds evolution is well demonstrated in the case of glyphosate-resistant (GR) weeds.

The adoption of herbicide-resistant crops, and no-tillage practices revolutionized the weed management practices in several major crops. The most common introduced trait was the bacterial CP4 gene endowing excellent resistance to glyphosate into major crops such as soybeans, maize, cotton and oilseed rape. These GR crops, known as RR – Roundup-Ready®, allowed growers to rely solely on the outstanding performance of glyphosate and base their weed control programs on a single post-emergent herbicide while neglecting the benefits of residual herbicides and soil cultivation. The evolution of GR weeds was inevitable due to the strong selection pressure employed by the repeated use of glyphosate particularly under zero tillage conditions. The dimensions of the damage caused by aggressive weeds such as *Conyza canadensis*, *Amaranthuspalmeri* and *Sorghum halepense* in soybean and cotton seriously threaten the sustainability of these crops in North and South America. The mechanism of GR in most plants is associated with compartmentation of the herbicide away from the target site in the chloroplasts whereas in some weeds such as *A. palmeri* the resistance is based on over expression of the target enzyme – EPSPS.

The fact that GR has evolved in countries where GM crops are not grown indicates that the resistance is not crop-dependent but rather a direct result of misuse of glyphosate by the farmer. Since a broad-spectrum herbicide such as glyphosate is a vital component of the weed management practices, it was proposed to slow down or even prevent further evolution of GR by using a combination of glyphosate with other MOA(e.g., paraquat) in mixture or in sequence as "double knock-down" treatments. This approach is hindered by the rapid evolution of multiple herbicide resistance. The recent introduction of the new GM crops stacked with two or more herbicide-resistance traits (e.g., glufosinate, 2,4-D, dicamba, HPPD), if used wisely, may offer the farmer new prospects in weed management but can turn failure due to misuse and multiple herbicide resistance. It becomes clear that in order to combat herbicide-resistant weeds and maintain sustainable farming, we should not rely on herbicides as the only way to control weeds. We should readopt weed management methods such as timely cultivation, crop density, rotation of crops and herbicides that lead to "good agricultural practices (GAP)".

Symposium – 4

Biological control – progress an future prospects in Asia-pacific region

Prospects for extending the success in the biological control of Parthenium weed in Australia into the Asia-Pacific region

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Parthenium, *Parthenium hysterophorus* (Asteraceae), an annual herbaceous plant native to the tropical Americas, is a major weed of tropical and subtropical regions of Australia, Asia, Africa and the Pacific. Parthenium affects agriculture, natural ecosystems, and human and animal health. Management options for Parthenium include chemical, physical and biological methods, and maintaining pasture cover through conservative livestock grazing pressure (Dhileepan 2009). Chemical and physical methods can provide some relief over the short term, but they are not effective in the longer term. Biological control is regarded as the most effective and economic method.

Biological control in Australia

Biological control of Parthenium in Australia commenced in 1977 and, since then, nine insect species and two rust fungi have been released (Dhileepan and Strathie 2009).All agents established at some localities, but the time taken for their establishment varied widely and ranged from one to 14 years. Among them, the leaf-feeding beetle, *Zygogramma bicolorata*, (Coleoptera: Chrysomelidae), the stem-galling moth, *Epiblema strenuana* (Lepidoptera: Tortricidae), the stem-boring weevil, *Listronotus setosipennis* (Coleoptera: Curculionidae), the seed-feeding weevil, *Smicronyx lututentus* (Coleoptera: Curculionidae), the root-feeding clear-wing moth, *Carmenta* nr. *ithacae* (Lepidoptera: Sesiidae) and the Parthenium summer rust, *Puccinia xanthii* var. *parthenii-hysterophorae (Pucciniales)* are now widespread and effective in controlling parthenium weed (Dhileepan and McFadyen 2012). The combined impact of these agents has resulted in significant reductions in the abundance and impact of parthenium in most situations and seasons, though serious infestations can still occur in Queensland, Australia.

Biological control in Asia-Pacific

Only a few of the agents proven to be effective in Australia have been introduced into other countries including India, South Africa, Ethiopia, Sri Lanka and Papua New Guinea (PNG). The leaf-feeding beetle, the only agent deliberately introduced against parthenium in India, now occurs widely in India and in the neighboring Pakistan and Nepal. The stem-galling moth and the summer rust, sourced from Australia, have been released in Sri Lanka, but so far there is no indication of their field establishment. The leaf-feeding beetle from Australia has also been released in PNG and Vanuatu. There is an increasing interest in the Asia-Pacific region in exploiting other biological control agents known to be successful in Australia.

CONCLUSIONS

Based on field host specificity, widespread establishment and damage levels in Australia, the stem-boring weevil, the seed-feeding weevil, the root-feeding clear-wing moth and the parthenium summer rust are the priority agents for introduction into India and other countries in the Asia-Pacific. Use of climate matching tools to identify climatically favorable release sites and adoption of community-based programs for rearing and release of biological control agents are recommended.

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The potential of fungal pathogens for classical biological control of invasive alien weeds in the Asia-Pacific region

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Plant pathogens are infamous for their negative impacts on plant health and generally associated with devastating crop epiphytotics and severe crop losses. However, it is this very nature – their detrimental impact combined with extreme host specialization - that can make "beneficial" plant pathogens highly effective agents for biological control of invasive weeds. Biological control of weeds, the use of natural enemies to control invasive plant populations, is environmentally benign, cost effective and sustainable with a proven track record for safety. Classical biological control (CBC) targets predominantly invasive alien weeds and is based on the principle to reunite introduced plant species with their co-evolved host-specific herbivores and/or pathogens, which have often been left behind in the weed's native range, to manage the invasive in its exotic range. Since the concepts of this approach were initially developed, and subsequently refined, by entomologists, arthropods have traditionally been the biological control agents of choice. Thus while the principles of CBC apply equally to plant pathogens this group of organisms has only been more recently considered and exploited for weed biological control. In addition to the classical approach whereby a biological control agent is mass-released once, or at most a few times, to build up a self-sustaining population controlling its host, certain plant pathogens can also be used in an inundative manner as a mycoherbicide. Mycoherbicides are usually based on native, rather than introduced fungal pathogens and used to control indigenous weedy plant species. Mass production and formulation of the selected pathogen, and usually commercialization, are key aspects of this control approach in which applications are regularly made early in the growing season to control an expanding weed population by causing a disease epidemic.

Within the Asia Pacific region Australia and New Zealand are the two countries most experienced in the use of biological control in integrated weed management, and fungal pathogens have featured amongst some of their most successful classical biocontrol agents released. In Australia effective control of rubber vine, *Cryptostegia grandiflora* (Apocynaceae), native to Madagascar, through release of the highly specific rust *Maravallia cryptostegiae*in1995 has averted the threat posed by the invasive to tropical ecosystems in Northern Queensland, as well as hugely benefitted Queensland's agriculture. For New Zealand a comparable "fungal" success was the release of the white smut fungus *Entyloma ageratinae* to control its Mexican host mistflower, *Ageratina riparia* (Asteraceae), an alien invasive threatening native woodland plant species. Given their long biological control history both countries have also been instrumental in the transfer of knowledge, technology and biological control agents in this geographic region. "Pathophobia" still prevailing in many countries and arthropods still constituting the majority of released agents has meant that this transfer has mostly involved insect agents. Nevertheless, fungal pathogens can have equally high potential to be employed on a wider scale against target weeds affecting several countries in the region. The rust pathogen *Puccina xanthii* controlling *Xanthium strumarium* (Asteraceae) in non-arid regions of Australia is under evaluation for control of the weed in Papua New Guinea and has also recently been introduced into the Cook Islands.

The white smut fungus could benefit Sri Lanka through control of mistflower, and the rust pathogens *Prospodium tuberculatum* and *Puccinia lantanae* recently introduced into Australia (only *P. tuberculatum*) and New Zealand against *Lantana camara* (Verbenaceae) could help India's, and other countries', extensive problem with this weed. However, not every fungal pathogen fits all and the suitability of fungal biocontrol agents has to be carefully evaluated for individual countries. For example the 'summer rust' *Puccinia xanthii* var. *parthenii-hysterophorae* released against *Parthenium hysterophorus* (Asteraceae) in Australia (2000) and South Africa (2010), was found to be unsuitable as a control agent for the weed in India due to its ability to attack the culturally important species marigold *Calendula officinalis* (Asteraceae).

One of the most recent fungal biocontrol agents promising to be a great success in the Asia Pacific region is the rust pathogen *Puccinia spegazzinii* employed for control of the invasive neo-tropical vine *Mikania micrantha* (Asteraceae).Initially released in India (2005) as the first ever pathogen officially introduced for weed biocontrol in this country, further releases of the rust have been made in Papua New Guinea, Fiji, Taiwan, the People's Republic of China, Vanuatu and, most recently, the Cook Islands. Another important biocontrol initiative in the region is the use of the pathogen *Colletotrichum gloeosporioides* f. sp. *miconiae,* a classical agent which is applied inundatively against the alien invasive *Miconia calvescens* (Melastomataceae) in Tahiti.

The Asia Pacific region has not only received numerous fungal weed biocontrol agents over the years but has also been the source of pathogens for biological control of invasive weeds elsewhere. Last year the rust *Puccinia komarovii* var. *glanduliferae* ex India has been approved for release in the UK for control of invasive Himalayan Balsam, *Impatiens glandulifera* (Balsaminaceae), and more research initiatives exploring the potential of the region's mycoflora for weed biocontrol are under way.

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Role of multi-trophic interactions in weed biological control – Its future

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Over the last few decades, investigations on insect-plant-pathogen interactions have been increasing (Caeser 2011; Moran 2004). Such interactions influence how plant communities affect herbivore/pathogen communities and in turn, how herbivore/pathogen affect the composition of plant communities. Such studies can form the interface between weed biological control and restoration of healthy, chemical-free environment.

Positive interactions in weed biocontrol

Insect herbivory makes plants susceptible to pathogen attack or plants suffering from phytopathogenic diseases may be destroyed by insect feeding (Ray and Hill 2012). For example, under field conditions, waterhyacinth, *Eichhornia crassipes* (Mart.) Solms. (Pontederiaceae) infested with the weevils *Neoechetina* spp. (Coleoptera: Curculionidae) or the moth *Niphograpta albiguttalis* (Warren) (Lepidoptera: Pyralidae) are more prone to the phytopathogen *Cercospora piaropi* (Tharp) (Mycosphaerellaceae), which is known to cause fatal leaf necrosis on the weed. Necrosis development isten-fold greater in insect attacked plants than those with pathogen alone (Moran 2004). Insects are known to carry spores of fungal pathogens by aiding the spread of diseases. For example, the beetle *Chrysolina hyperici* Forest. (Coleoptera: Chrysomelidae) can augment biocontrol of St. Johnswort *Hypericum perforatum* L. (Clusiaceae) seedlings by transmitting the fungal pathogen *Colletotrichum gloeosporioides* f. sp. *hypericum* (Penz.) Penz. and Sacc. (Glomerellaceae) during foraging and feeding (Morrison *et al.* 1998).

Negative interactions in weed biocontrol

Multitrophic interaction may not always prove beneficial to weed biocontrol. Weevil *Oxyops vitiosa* Pascoe (Coleoptera: Curculionidae) prefer laying eggs on non-infected weed *Melaleuca quinquenervia*(Cav.) S.T. Blake (Myrtaceae). Percentage of egg-laying was reduced when females were made to oviposit on weeds infected by the rust fungus *Puccinia psidii* G. Wint. (Pucciniaceae). Both the weevil and the fungus can cause damage to the weed when they attack individually (*Rayamajhi et al.* 2006). Feeding by leaf-beetle *Gastrophysa viridula* Degeer (Coleoptera: Chrysomelidae) on *Rumex obtusifolius* L. (Polygonaceae) induced a systemic resistance that reduced the subsequent infection by the rust *Uromyces rumicis* (Schum) Wint (Pucciniaceae) (Hatcher and Paul 2001).

Competitive interactions between biological control agents may also impact weed control mechanism. For example, *Galerucella calmariensis* (L.) and *G. pusilla* (Duftschmidt) (Chrysomelidae), the biological control agents of purple loosestrife, *Lythrum salicaria* (L.) (Lythraceae), feed primarily on the foliage. After heavy defoliation, the flowering of purple loosestrife is suppressed, resulting in a food shortage for another control agent, *Nanophyes marmoratus* Goeze (Coleoptera: Brentidae), a flower-feeder (*Julien and Griffiths 1998*).

CONCLUSION

Often a particular biological control agent is successful in one place and less or unsuccessful elsewhere. Such failures have been associated to various reasons from unpredictable climate causing slow build of biological control agent population, natural calamities and inappropriate application of herbicide, etc. But one aspect has been highly ignored is the interaction between the plant and associated biological control agent.

Studies on multi-trophic interaction may hold great importance in weed biological control and can introduce a new era of progress in weed management research. Additive or synergistic effects among herbivores and phytopathogens are necessary to achieve biological control of hardy weeds. Use of chemicals for weed control can be reduced if biological control agents are utilized in a proper way. The few analyses given in this article highlights the efficacy of muti-trophic interactions in eradicating invasive weeds more effectively. Extensive studies involving multi-trophic interactions should be an essential part of pre-release evaluation studies. This will tremendously enhance the success rates of biological control of noxious weeds.

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The response of an invasive weed and its biological control agent under a changing climate of CO_2 enrichment: Management challenges for the future

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Parthenium weed (*Parthenium hysterophorus* L.) is an invasive weed of global significance that has become a major weed in Australia and many other parts of the world (Adkins and Shabbir 2014). Little information is available on the effects of CO_2 enrichment upon the weed's growth and the performance of one of its biological control agent, a stem galling moth (*Epiblema strenuana* Walker) used in the management of this weed. Therefore, any information on CO_2 enrichment responses will help develop better management strategies for this weed. The objective of the present study was to determine how much more effective (or otherwise) the biological control agent will be in managing parthenium weed when under CO_2 enrichment.

METHODOLOGY

Plants were grown in two growth chambers, one set at ambient (380µmol/mol) and the other at elevated CO_2 (550 µmol/mol). When the plants were 6-weeks old, the stem galling moth larvae were removed from field collected galls and applied to half of the plants in each chamber, at a rate of two larvae per plant. The seed produced was counted and the proportion that was filled determined by x-ray analysis (Faxitron MX-20, Illinois, USA). After 110 days of growth, plant height, basal stem diameter, above ground biomass, number of branches , number of seeds and the leaf gas exchange rate were determined (only the results for biomass and seed production described here).

RESULTS

Elevated CO_2 led to a significant increase (38%) in the weed's biomass production. The stem galling moth reduced the biomass production at both an ambient (36%) and elevated CO_2 (45%). More seeds (37%) were produced under elevated CO_2 (Plate 1). More branches (50%) were produced in response to stem-galling moth damage (data not shown), and this led to significantly more seeds per plant, however, a proportion (45%) were found not to be filled.

CONCLUSIONS

Elevated CO_2 has a profound positive effect upon both the growth and seed production of parthenium weed. The biological control agent had the ability to reduce the height and biomass of parthenium weed plants under both ambient and elevated CO_2 and these plants produced less seeds and seed fill. The biological control agent would remain effective in managing weed under climate change of CO_2 enrichment.

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Progress and prospects of biological control of weeds in India

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Biological control of weeds involves the use of living organisms to control a weed population to keep at or below desirable level without affecting useful plants. It includes use of insects, pathogens, nematodes, competitive plants, fishes etc. Biological control method has been found very successful on large infestation of a single weed species, which usually occurred in wasteland, range lands or in water bodies. Unfortunately, biological weed control has not been found very successful to control weeds in crop situations. Natural biological control by pathogens, predators and parasites of agricultural pests has been occurring since the beginning of evolutionary process of crop plants. After the Second World War, the success of chemical pesticides such as DDT and 2, 4-D became known and eventually led to use of herbicides in crops. Since then, synthetic pesticides development and use took enormous leap in agriculture. However, the public perception gradually changed due to deleterious effects of pesticides. During the past three decades, several attempts have been made world over to manage problematic weeds through the use and manipulation of biological control agents. This paper elucidates the information on classical biological control in particular and other ways of biological control in general in India.

Problematic weeds which need biological control approaches in India

The exotic weeds in the absence of their natural antagonists, which are left behind when the weeds leave their original home, cause unprecedented damage and interfere with cultivation of crops, productivity of land, biodiversity and ecosystem resilience, and grazing and livestock production, cause ill health in humans and livestock, fires in heavily invaded areas, choking of navigational and irrigation canals, and reduction of available water in water bodies. Many aquatic weeds like *Eichhornia carassipes* (Pontenderiaceae), *Salvinia molesta* (Salviniaceae), *Hydrilla verticillata* (Hydrocharitaceae), *Pistia stratiotes* (Araceae), *Ipomoea aquatica* (Convolvulaceae)etc. are problematic in India in different type of aquatic bodies. The famous Dal lake in Srinagar has succumbed to the attack from many aquatic weeds like *Hydrilla*, *Lemna* (Araceae), *Azolla* (Salviniaceae) etc. This situation has led the Government to employ weed harvester and manual cleaning by boats throughout the year. Irrigation canals in Rajasthan, Punjab and Haryana are regularly chocked by emerged (*Typha* spp., Typhaceae) and floating (*E. carassipes*) weeds. Two rivers in Jamshedpur (Jharkhand) were badly choked with water hyacinth which caused tremendous increase in malaria and dengue cases. *Parthenium hysterophorus* (Asteraceae) has invaded about 35 million hectares of land in India, responsible for loss of crop productivity, biodiversity and many health problems in human beings (Sushilkumar and Varshney 2010). *Lantana camara* (Verbenaceae), *Chromolaena odorata* (Asteraceae) and *Mikania micrantha* (Asteraceae) are causing menace in forests.

History of biological control in India

The history of biological control of weeds dates back to the seventeenth century and since then a great deal of success has been achieved in biological methods of weed control. In India, systematic biological control research started with the establishment of the Indian station of Commonwealth Institute of Biological Control (CIBC) at Bengaluru in 1957 with need based 23 substations at various places in different states. The All-India Co-ordinated Research Project on Biological Control of Crop Pests and Weeds (AICRP-BC&W) was established in 1977 with 10 centres which increased to 16 under the aegis of Project Directorate of Biological Control (PDBC) under Indian Council of Agricultural Research (ICAR). The PDBC was later upgraded as National Bureau of Agriculturally Important Insects (NBAII) to act as a nodal agency for biological control of crop pests including weeds. The Bureau is now re-named as National Bureau of Agricultural Insect Resources (NBAIR). Meanwhile, National Research Center for Weed Science (NRCWS) came into existence in 1989 at Jabalpur with a modest beginning of biological control of weeds in 1990s. The centre upgraded to Directorate of Weed Science Research in 2009 and renamed as Directorate of Weed Research (DWR) in 2015. Now with the change in mandate of NBAIIS, the DWR shall deal on biological control issues of weeds in India.

Successful examples of classical biological control of weeds in India

Work on biological control of weeds in India in general and *P. hysterophorus* in particular has been dealt by Sushilkumar (1993) and Singh (2004) and Sushilkumar (2009), respectively. So far in India, about 30 exotic weed biological control agents have been introduced into quarantine of which six could not be released in the field, 3 could not be recovered after release while 21 were established and recovered. From these established biological control agents, 7 are providing excellent control, 4 substantial control and 9 partial control. Biological control agents, mainly insects, provided excellent control of prickly pear, *Opuntia elatior* and *O. Vulgaris* (Cactaceae) by *Dactylopius ceylonicus* and *D. opuntiae* (Hemiptera: Dactylopiidae); *S. molesta* by weevil, *Cyrtobagous salviniae* (Coleoptera: Curculionidae); *E. carassipes* by weevils *Neochetina bruchi* and *N. Eichhorniae*(Coleoptera: Curculionidae) and galumnid mite *Orthogalumna terebrantis* (Acari: Galumnidae); *P. hysterophorus* by chrysomelid beetle *Zygogramma bicolorata* (Coleoptera: Chrysomelidae). Some introduced biological control agents did not prove successful but are providing partial control like of *L. camara* by *Ophiomyia lantanae* (Diptera: Agromyzidae), *Teleonemia scrupulosa*(Hemiptera: Tingidae), *Diastema tigris* (Lepidoptera: Noctuidae), *Uroplata girardi* (Coleoptera: Chrysomelidae), *Octotoma scabripennis* (Coleoptera: Chrysomelidae)and *Epinotia lantanae* (Lepidoptera: Tortricidae); *C. odorata* by *Pareuchaetes pseudoinsulata*

(Lepidoptera: Arctiidae); *Ageratina adenophora* by *Procecidochares utilis* (Diptera: Tephritidae); submerged aquatic weeds such as *Vallisneria* spp. (Hydrocharitaceae) and *H. verticillata* in fish ponds by grass carp. Singh (2004) concluded maximum degree of success by classical biological control agents in India has been of aquatic weeds (55.5%) followed by homopterous pests (46.7%) of crop pests and terrestrial weeds (23.8%).

Prospects of biological control of weeds

There are many biological control agents which have been introduced in other countries and have shown varying degrees of success through combined effects. In Australia, 11 biological control agents have been introduced against *P. hysterophorus* alone. Such successful biological control agents need to be introduced in India against some of the problematic weeds like *P. hysterophorus*, *E. carassipes*, *P. stratiotes*, *Alternanthera philoxeroides* (Amaranthaceae) etc.

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Prospects of biological control of major invasive alien weeds in forest ecosystems in India

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Invasive alien plant species that are non-native to a country or a specific ecosystem, which are introduced purposely or accidently into a newer environment heavily colonize the invaded habitats in the absence of natural enemies and adversely affect the functioning of that ecosystem. Their introduction to or invasion of forest ecosystems importantly protected and environmentally sensitive areas impose enormous economic loss or damage in terms of ecological destruction and detriment to wildlife and human health. India is one of those countries invaded by many noxious invasive alien weeds over a century and half. Spread and severity of these weeds in agricultural lands and in different forest ecosystems, in particular in the protected areas of Western Ghats and rain forests of north-eastern states has become serious in the recent times, causing environmental concerns. India is rich in biodiversity and has wide range of bio-geographical zones with varied climatic conditions. There are about 500 wildlife sanctuaries, 90 national parks and 13 biosphere reserves. Nearly 1800 plant species are known as alien to India. Of which species such as *Lantana camara* (Verbenaceae), *Mikania micrantha* (Asteraceae), *Chromolaena odorata* (Asteraceae) and *Mimosa pudica* (Fabaceae) are of social, economic and environmental importance as they have invaded many wildlife preserves and natural forests.

These invasive weeds are also known to be dangerous in teak, eucalypts and coffee plantations in this country as they severely affect the establishment and growth of the young plantations and also reported to have allelopathic effect, inhibiting the growth of the native vegetation. Though the bad effects and the threat posed by these weeds to the environment have been talked about and highlighted much on number of occasions, no serious attempt has been made to look at the problems related to these alien invasive species and to plan for sustained and effective management strategies. While mechanical and chemical methods of management of these species are suggested by many researchers, except for some preliminary attempts to introduce selective biological control agents against these invasives, no systematic and concerted efforts are made to tests and make use of the proven biological control strategies available elsewhere. This paper emphasizes the need for a focused, coordinated and sustained effort at the national level to explore the possibilities of importing, testing and introduction of the proven biological control agents. Importance of climate matching in successful introduction and establishment of the biocontrol agents is also highlighted in the paper.

Powder formulation of *Phomaherbarum* as biological control of goose grass *(Eleusine indica)*

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Goosegrass (*Eleusine indica*, Poaceae) is a noxious weed in oil palm plantations in Malaysia. The weed is listed as one of the 10 worst weeds of the world (Lim and Ngim 2000). *E. indica* competes strongly with oil palm for nutrients, water, light and space (Mohamad *et al*. 2010). Currently, application of herbicide is the most effective method to kill *E. indica* in plantation (Rusli *et al.* 2014). A consequence of the extensive use of herbicides has been the emergence of herbicide resistance in weed species in oil palm plantations, orchards and vegetable farms. Therefore, an alternative method needs to be sought, using microbes as biological control agents, which is more environmentally friendly. The fungi of the genus *Phoma* have potential as biological control agents of weeds; examples include *Phoma herbarum* Westendorp for *Taraxacum officinale* Weber in turf and *P. sorghina*on poke weed (Venkatasubbaiah *et al*. 1992; Li *et al.* 2011; Neumann and Boland 2002). We have developed a powder formulation of *P. herbarum* which has potential for biological control of *E. indica*.

Nursery efficacy test

A nursery trial was conducted in Malaysian Palm Oil Board (MPOB), Bandar Baru Bangi, Malaysia. Two treatments (treated and untreated) were carried out, where each treatment consisted of 20 pots per replication with three replicates using randomized complete block design. The effect of powder formulation of *P. herbarum* was noticeable at 14 days after treatment and continued to increase at 21 days and 28 days after applications. At the end of the experiment (28 days), 90% of the *E. indica* treated with *P. herbarum* was killed whereas no mortality was observed for the control treatment (Table 1).

Field efficacy test

A field trial was conducted in an young oil palm planting (12 months) in Bandar Baru Bangi, Selangor. The trial was set up in three quadrats (2 m x 5 m) where powder formulation of *P. herbarum* was treated and replicated three times in a completely randomized design. In each quadrat, there were approximately 20 *E. indica*. Mortality of *E. indica* increased significantly at 14 days after treatment and thereafter (*Table 2*). The mortality rate of *E. indica* continued until 28 days and stabilised at 80%. The study also recorded that 10% of the untreated *E. indica* died due to aging. It was also observed that the treatment did not control the weed's root system. *E. Indica* regenerated 42 days after treatment in all treated quadrats. The same observation was made when conidial suspensions of two leaf-spotting pathogens, *Bipolaris setariae* (Saw.) and *Pyricularia grisea* (Cke.) Sacc. were applied on *E. indica* (Riding 1988). In comparison, regeneration of *E. indica* was recorded at 21 days after treatment when conventional herbicides mixtures were used (Rusli *et al*. 2014).

Table 1. Effects of the powder formulation *P. herbarum* on *Eleusine indica* in a nursery trial

Treatment	Mortality of *E. indica* (%)			
	7 days	14 days	21 days	28 days
P. herbarum at 10^6 conidial / ml	0	30a	80a	90a
Untreated control	0	0b	0b	0b

Different letter within the same column denotes significant difference($p<0.05$) by t-test

Table 2. Effects of the powder formulation of *Phoma herbarum* on *Eleusine indica* in a field trial

Treatment	Mortality of *E. indica* (%)				
	7 days	14 days	21 days	28 days	35 days
P. herbarum at 10^6 conidial / ml	0	30a	70a	80a	80a
Untreated *E. Indica* (control)	0	0b	0b	0b	10b

A different letter within the same column denotes significant difference ($p<0.05$) by T-Test

CONCLUSIONS

A stable formulation of *P. herbarum* has been developed for the control of *E. indica.* The formulation effectively controls up to 80% of this weed. Since the weeds re-grew, repeated applications of the formulation are needed. The powder formulation of *P. herbarum* is relatively inexpensive to produce.

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Biological control agents of invasive alien plant species in Nepal

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Rapid spread of invasive alien plant species (IAPS) has negative ecological and socio-economic consequences both in developed and developing countries of the world. There are nearly two dozens of IAPS in Nepal. As a part of integrated approach to control IAPS, various biological control agents have been released in different parts of the world. In Nepal, biological control agent has been reported only for two IAPS; a fungal parasite *Passalora ageratinae* Crous and AR Wood (Mycosphaerellales: Mycosphaerellaceae) and a stem galling insect *Procecidochare utilis* Stone (Diptera: Tephritidae) for *Ageratina adenophora* (L.) King and Robinson, and a winter rust *Puccinia abrupt* Dietel & Holw. var. *partheniicola* (H.S. Jacks.) Parmelee (Pucciniales: Pucciniaceae)and a leaf feeding beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) for *Parthenium hystrophorus* L. (Winston *et al.* 2014). These biological control agents were not released intentionally in Nepal but arrived from the neighboring countries, particularly India, through natural dispersal (Shrestha *et al.* 2015). In Nepal, spatial pattern of the distribution of these biological control agents is largely unknown.

METHODOLOGY

During nation-wide survey of IAPS along roadside vegetation conducted during 2013 rainy season (June-August), we recorded the presence of biological control agents of *A. adenophora* and *P. hysterophorus*, and assessed their impacts on these IAPS. Roadside vegetation of 4200 km road, which included all national highways and district level feeder roads, was scanned. IAPS and their biological control agents were examined at an interval of 10 km in plain and 5 km in hilly regions. Some opportunistic observations between these locations were also made.

RESULTS

We did not find *P. ageratinae* of *A. adenophora* while the winter rust *P. abrupta* var. *partheniicola* of *P. hysterophorus* was found localized only in Kathmandu valley. Damage by winter rust on *P. hysterophorus* was insignificant. Stem galling insect (*P. utilis*) of *A. adenophora* and leaf feeding beetle (*Z. bicolorata*) of *P. hysterophorus* were frequently present. Out of 293 locations where *A. adenophora* was present, the stem galling insect was present at 193 locations (66%). However, the impact was insignificant. At a given location, stem galling was found nearly in 1/4th of the stem and the damage on the plant growth was only marginal without noticeable damage at population level. Out of 362 locations where *P. hysterophorus* was present, the leaf feeding beetle was present at 144 locations (40%) and the damage on the plant was noticeable (>10 leaf damaged) at nearly half of these locations (Fig. 1).

Though the stem galling insect has been present in Nepal for more than four decades, its impact on the weed has been insignificant. But with less than a decade of residence time of leaf feeding beetle in Nepal, its damage is noticeable and likely to increase in future with natural population build-up.

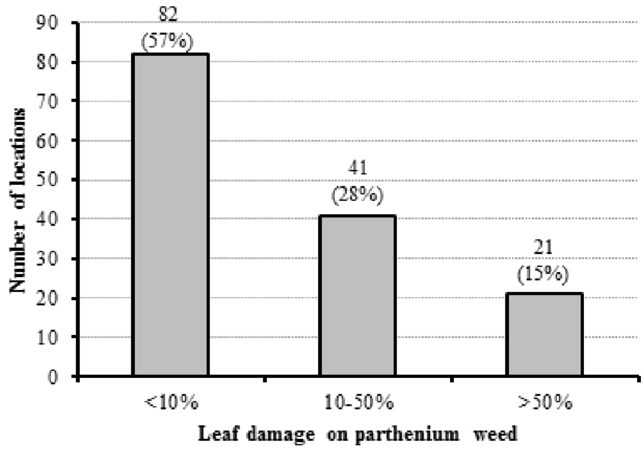

Fig. 1. Number of survey locations with varying levels of leaf damage on parthenium weed (*Parthenium hysterophorus*) by the leaf feeding beetle. The value inside parenthesis above each bar is the percentage of total locations

CONCLUSIONS

Biological control agents of two invasive alien plant species *A. adenophora* and *P. hysterophorus* arrived and have spread naturally in Nepal with apparently no damage to the former and noticeable damage to the later.

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Impact of native herbivores on the survival and growth of prickly acacia in semi-arid regions of India

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Vachellia nilotica subsp. *indica* (Benth.) Kyal. & Boatwr. (syn: *Acacia nilotica* subsp. *indica*) (Fabaceae), commonly known as prickly acacia, is a Weed of National Significance in Australia affecting over seven million hectares of grazing land and 2000 kilometers of bore drains in Northern Australia. The effective study in the native range to identify potential agents underpins all efforts in classical biological control of weeds (Marohasy 1995). The biological agents that exhibit both a high degree of host specificity and a potential to be injurious are a very limited resource and must therefore be watchfully studied and measured (Palmer 1996). During the course of the exclusion trials laid in arid and semi-arid areas of Rajasthan and Gujarat (India), we have examined certain parameters like plant height (longest shoot), number of shoots, number of leaves, basal stem diameter and plant biomass(above-ground). We have also recorded the proportion of seedlings with combined herbivores attack, number of insect herbivores per seedlings, proportion shoot and leaf area damaged in arid and semi-arid areas of Rajasthan and Gujarat, in India.

METHODOLOGY

Prickly acacia (*V. nilotica* subsp. *indica*) is known to be facultative deciduous, and hence it is widely believed that leaf-feeding insects are unlikely to have any major negative impact on mature and established plants. Exclusion trials using insecticides were conducted at two sites (Gujarat and Rajasthan) in the native range to identify most damaging insects and quantify their impacts on seedling survival and growth. In each trial sites (Gujarat and Rajasthan) similar sized seedlings (around 500 in each site; 12 weeks old) raised from field-collected seeds or from nurseries were used in the field experiment. For each seedling, number of shoots, the shoot length, number of leaves, basal stem diameter and total wet weight were recorded and then assigned randomly to one of the two main treatments (exposed to native insect herbivoress and excluded from insect herbivores using insecticides). The experiment was repeated over two years and at the end of each year all plants were harvested after recording the following parameters as per experimental design: (1) plant height (longest shoot), (2) number of shoots, (3) number of leaves, (4) basal stem diameter and (5) plant biomass (above-ground). Simultaneously, a separate trial was carried out in the glasshouse (20 seedlings sprayed with insecticides and 20 seedlings sprayed with water, at fortnightly intervals) to ascertain that the insecticides applied will either retard or enhance the plant survival or growth. The impact of various treatments (insect excluded vs. insect exposed) and sub-treatments (under shade vs. under direct sun)over time (at 12, 24, 36 and 48 weeks) on plant parameters were analysed using analysis of variance (ANOVA), and means were compared using Fisher's least significant differences at 0.05 probability. All analyses were performed using SigmaStat 3.5 (Systat Software Inc., Richmond, CA, USA).

RESULTS

Plant height or shoot length

Statistical analysis of data from 12 to 48 weeks old seedlings revealed that the mean height of the seedlings was highest in the treated seedlings (insect-excluded) maintained under canopy (126.92 cm) at Gandhinagar (Gujarat) followed by treated (insect-excluded) seedlings maintained under canopy (126.21 cm) at Bhuj (Gujarath). Whereas, minimum height was recorded with treated (insect-excluded) seedlings maintained under canopy (79.6 cm) in Nadiad (Gujarath) followed by treated (insect-excluded) seedlings maintained under sun (89.4 cm) in Jodhpur (Rajasthan). The mean height of other treatments and trial ranged between 68.2 and 70.4 cm. At the interval of 12, 24, 36 end of the trial (48 week), the plant height was affected by the type (TUC: MS5576.12, $F=42.04$, $P < 0.001$; TUS: MS2195.1201, $F=15.71$, $P < 0.001$; UTUC: MS 1198.40, $F=19.22$, $P < 0.001$; UTUS: MS841.73, $F=6.85$, $P < 0.001$).

Number of shoots

Maximum numbers of shoots were recorded in treated seedlings of 48 weeks old seedling kept under the *V. nilotica* canopy (13.24) at Bhuj followed by untreated seedlings exposed to *V. nilotica* canopy (12.88) at Jodhpur. While the minimum numbers of shoots were recorded in treated seedlings kept under canopy (5.12) at Nadiad followed by untreated seedlings kept under the sun at Nadiad (5.16). At the interval of 12, 24, 36 end of the trial (48 week), the plant number of shoots was affected by the type (TUC: MS152.73, $F=14.83$, $P < 0.001$; TUS: MS33.34, $F=3.41$, $P = 0.002$; UTUC: MS133.41, $F=14.74$, $P < 0.001$; UTUS: MS45.21, $F=6.91$, $P < 0.001$).

Basal stem diameter

For the 48 weeks old seedlings, the mean value was 0.52 cm to 0.70 cm in Gujarat and Rajasthan. The basal stem diameter was recorded on maximum in treated seedling kept under *V. nilotica* tree canopy and untreated seedling exposed to sun (0.70) at Nadiad. At the interval of 12, 24, 36 end of the trial (48 week), the plant basal stem diameter was affected by the type (TUC: MS0.05, $F=4.30$, $P < 0.001$; TUS: MS0.02, $F=2.91$, $P = 0.007$; UTUC: MS0.01, $F=1.12$, $P = 0.35$; UTUS: MS0.08, $F=10.34$, $P < 0.001$).

Number of leaves

The maximum number of leaves (81.48) was recorded in 12 to 48 weeks old seedlings which were treated and exposed under sun followed by untreated under canopy (78.24) at Junagarh trial site while minimum in treated seedlings kept under canopy (72.08) at Gandhinagar followed by (72.80) at same treatment at Nadiad site. The specific data of 48 week old seedling revealed that the number of leaved varied from 56.52 to 103.53 in treated and kept under the *V. nilotica* tree canopy at Desuri and treated exposed to direct sun at Nadiad. At the interval of 12, 24, 36 end of the trial (48 week), the plant number of leaves was affected by the type (TUC: MS5743.83, $F=19.93$, $P < 0.001$; TUS: MS2964.28, $F=10.55$, $P < 0.007$; UTUC: MS3729.50, $F=10.79$, $P < 0.001$; UTUS: MS2828.93, $F=11.65$, $P < 0.001$).

Plant biomass above ground: The mean of plant biomass (wet weight)in 12 to 48 week old seedling showed maximum and minimum in 28.23 to 18.08 on untreated and kept exposed to sun at Gandhinagar and treated exposed to direct sun at Gandhinagar respectively. At the interval of 12, to 48 weeks old seedlings, the plant biomass above ground was affected by the type (TUC: MS662.51, F=120.30, P < 0.001; TUS: MS160.89, F=16.68, P < 0.001; UTUC: MS106.56, F=14.30, P < 0.001; UTUS: MS257.25, F=38.30, P < 0.001).

CONCLUSION

The various parameters of prickly acacia, *V. nilotica* seedlings of different age groups *i.e.* number of shoots, number of leaves, root length and biomass above ground and below ground were maximum in treated seedlings as compared to untreated in the exclusion trails, carried out in arid and semi-arid areas of Rajasthan and Gujarat.

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Biological control programs of major invasive weeds in the Western Pacific

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Invasive plant species are one of the most serious threats to biodiversity and sustainable development in the Western Pacific. Biological control has proven to be effective in managing some of the perennial weeds. *Lantana camara* (Verbenaceae) was one of the plants recognized as an invasive weed by the Invertebrate Consultants Committee for the Pacific of the National Research Council and its natural enemies were introduced from Hawaii starting in 1948. The Siam weed, *Chromolaena odorata* (Asteraceae) was targeted for biological control in 1983, ivy gourd, *Coccinia grandis* (Cucurbitaceae) in 2002, *Mimosa diplotricha* (Mimosaceae) in 2008, and *Micania micrantha* (Asteraceae) in 2011.

METHODOLOGY

In 1948 and 1949 for biological control of lantana, *Telenomus scrupulosa* (Hemiptera: Tingidae), *Epinotida lantana* (Lepidoptera: Tortricidae), *Lantnophaga pussillidactyla* (Lepidoptera: Pterophoridae) and *Ophiomyia lantanae* (Diptera: Agromyzidae) were introduced from Hawaii to Pohnpei (Gardner 1956) and subsequently these and other agents were introduced to other islands in Micronesia. For biological control of *C. odorata*, the moth *Pareuchaetes pseudoinsulata* (Lepidoptera: Arctiidae) was introduced from India and Trinidad and became established on Guam in the 1980s. The gall fly *Cecidochares connexa* (Diptera: Tephritidae) was introduced from Indonesia in 1998 and established on Guam in 2002 and other Micronesian islands in succeeding years (Cruz *et al.* 2006). For biological control of *C. grandis*, the natural enemies *Acythopeus cocciniae* and *Acythopeus burkhartorum* (Coleoptera: Curculionidae) and *Melittia oedipus* (Lepidoptera: Sesiidae) were introduced to Guam (Muniappan *et al.* 2009). The two weevils, *A. cocciniae* and *A. burkhartorum* were field released in various locations on Guam in 2003 and 2004, respectively (Bamba *et al.* 2009) and *M. oedipus*was released in 2007 (Muniappan *et al.* 2009). The psyllid, *Heteropsylla spinulosa* (Hemiptera: Psyllidae) was collected from Pohnpei and Palau and field released on Guam in 2008 for control of *M. diplotricha*. The rust fungus *Puccinia spegazzinii*collected from Fiji was introduced to Guam in 2011for the control of *M. micrantha*.

RESULTS

A limited suppression of lantana has taken place in Micronesia. Considerable control of *C. odorata* was achieved by the moth, *P. pseudoinsulata*) (Muniappan *et al.* 2005) and the gall fly, *C. connexa* (Reddy *et al*. 2013). The natural enemies *M. oedipus*and *A. cocciniae* effectively controlled *C. grandis* in Guam by 2010. However, *C. grandis* infestation was still seen in Saipan and Rota. Although *H. spinulosa* established successfully at the release sites on Guam, it has yet to provide significant control of *M. diplotricha*. Therust fungus *P. spegazzinii* introduced in 2011 is yet to be established on Guam.

CONCLUSION

The biological control programs have provided satisfactory (*C. coccinia* and *C. odorata*) to adequate (*L. camara*) control of a few invasive weeds in the Western Pacific. However, biological control agents introduced for *M. micrantha* and *M. diplotricha* have either not established or not effective and hence additional efforts for their establishment and spread are required.

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Symposium – 5

Utilization of weeds as bio-resources

Liabilities or assets? Perspectives on weeds and their values

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Many people have strong negative attitudes towards weeds, and a tendency to label a large number of potentially useful plant resources as invasive species, which should be controlled at any cost, while ignoring considerable evidence of the uses of these plants. This attitude may stem from the strong, traditional focus on the negative impacts of weeds, including the losses of agricultural production caused by weeds, and the threats they may pose to biodiversity. The plants in question are mostly 'colonizers', which have the capacity to rapidly occupy human-modified environments. The focus in most countries has been so much on waging a protracted (and unwinnable) war on weeds that land managers have tended to overlook the potential of using these plants as resources.

The literature in a number of fields provides evidence that many colonising taxa may form worthy resources in diverse areas of human interest. These include their traditional uses as food, for both humans and animals, and continued use as medicinal and therapeutic plants. There is considerable, global interest at present, in obtaining pharmaceuticals from many taxa occupying disturbed habitats.

Other major areas of significant interest include the use of the colonising strengths of several species in the remediation of water and terrestrial environments that have been damaged by human activities. Among some outstanding prospects are the potential to use aquatic species, such as water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in pollution removal, and the use of some strong colonisers in wastewater treatment systems, or in the rehabilitation of riparian zones of watercourses and rivers. The common reed [*Phragmites australis* (Cav.) Trin. ex Steud.] and cattails (*Typha* spp.) are examples of such taxa. Globally, there is also considerable interest in using the large biomass produced by these species in a variety of beneficial ways, including as raw materials for a range of products and as biofuels of the future (biochar) and compost.

In addition, there are many opportunities for using colonising plants in phyto-remediation, to scavenge soil pollutants. Furthermore, the awareness of the role of weeds as part of biological diversity is increasing, and there is continuing interest in creating more sustainable farming systems, in which colonising species are appreciated.

There are also significant opportunities to further exploit chemical warfare between plants (allelopathic phenomena) in beneficial ways. These include the discovery of new bioactive chemicals and the use of allelopathic plant residues within low input agricultural systems. Many colonising plants are useful in providing such benefits.

The conflict between humans and weeds will continue, so long as humans modify ecosystems. However, a fresh look at the potential of 'co-existing' with weeds and using them as resources is overdue, given the many possibilities demonstrated. In many cases, the focus is on managing problematic species in specific situations, rather than on their utilization. However, if land managers can be led to appreciate the extraordinary strengths of the colonising taxa, this will allow a better integration of these species into our economies. Improved understanding of the causes of biological invasions should help to reduce the current confusion and negative attitudes towards invasive species.

This Symposium will discusses the above viewpoints, and provide examples to illustrate that not all weedy taxa are bad all the time, just because they may interfere, under certain circumstances, with human interests.

Weed utilization in Japan: A history

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Weeds have been recognized as wild plants growing most closely around human beings, while they have been eliminated as harmful pests in agricultural production in Japan. Throughout the history of Japan, weeds have been utilized as substitute foods, herbal medicines, green manures, materials of industrial crafts, resources for producing new crops and so on. Particularly, since Edo period (1603-1868) when a Japanese word "Zassou" meaning arable weed was used first in 1828, a vast amount of historical literature exists in Japan. The Japanese use of plant and weed utilization were published under major topics, such as advancement of agricultural technologies, food shortages as a result of poor harvests and the spread of herbal medicines introduced from China. Adding to the past history of utilization of plants and weeds, accumulated over times, studies on the topic have been activated from 1980s in the Weed Science Society of Japan (established in 1962), because increases in food production was the major subject of agricultural sciences including Weed Science in that period just after the Second World War. In this paper, the experiences of plant and weed utilization mainly as substitute foods, in literatures and activities in WSSJ are discussed along with the importance of promoting the subject of weed utilization through the sharing of knowledge of accumulated experiences.

Eco-friendly wastewater treatment for reuse in agriculture – An innovative initiative of Indian Agricultural Research Institute

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Oxidation pond or activated sludge process are the two most commonly deployed wastewater treatment technologies in India. However, these processes are expensive and require complex operations and maintenance. In view of these limitations, constructed wetland technology has been receiving greater attention in recent years. However, the rate of adoption of wetland technology for wastewater treatment in the developing countries has been low due a general belief that these technologies have large land area requirement. Batch-fed wetland systems with shorter hydraulic retention times (HRTs) have generally been found to translate into smaller land requirement and thus have an implication for their better acceptability in developing countries.

Keeping this in view, a batch fed (<1-day HRT) vertical sub surface flow wetland technology based municipal waste water treatment plant of 1500-LPD capacity was developed at the sewage plot site of the Indian Agricultural Research farm. The pilot plant is in operation since November 2009 and is being continuously monitored for nutrient/ heavy metal (pollutant) mass reduction efficiencies. Long term average pollutant mass reduction efficiency of the pilot system illustrated its capacity to reduce wastewater turbidity and nitrate, phosphate, potassium concentrations by up to 81, 68, 48 and 47%, respectively. Planted wetland systems, in general, seemed to be having an edge over the unplanted ones. Nutrient removal efficiencies seemed to be higher for the *Phragmites karka* based wetland systems. The *Typha latifolia* based systems, on the other hand, were observed to be associated with higher oxidation potential and thus higher sulphate reduction efficiencies (50.5%).

These systems also seemed to be associated with significantly higher Ni (62%), Fe (45%), Pb (58%), Co (62%) and Cd (50%) removal efficiencies. A comparison of ecological footprint and sustainability of the experimental wetland systems vis-a-vis a hypothetic conventional sewage treatment plant (STP) showed that the experimental wetland systems were 1500 times more sustainable. Based on these experiences, the technology has been recently upscaled to a 2.2 MLD horizontal sub-surface flow system for treating sewage waters from Krishi Kunj colony, adjoining IARI campus. The up-scaled system has potential to irrigate 132 ha land area of the Indian Agricultural Research farm.

Allelochemicals and natural products from weeds

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In weed management, allelopathy has three different approaches. One is allelopathy of weed as one of the detrimental effects of weeds on crops; and the other is the reciprocal effect - allelopathy of cropswhich can inhibit the growth of weeds. Utilization of allelopathic cover crop to inhibit the growth of weed is now distributing as an alternative way of weed control. Third field is to make new herbicides from allelochemicals. In this article, I provide an account of research that summarize the possibility of using allelochemicals from weeds and their applications in weed science.

Compost and vermicompost making from weeds: A simplest way of utilization

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Negative impacts of weeds are well known. Through these direct or indirect effects, weeds often increase the cost of farming and decrease the value of agricultural land and produce. In many cases, weeds are responsible to threaten the biodiversity of landscapes, forest, national parks and water bodies besides depletion of crop productivity and deteriorating environment. In opposite to negative impacts, weeds are also known to have many positive impacts including their use as compost and vermicompost (Kim *et al.* 2007, Varshney and Sushilkumar 2009, Chandrasena 2014).

Compost making from weeds

Complete killing of weed seeds is a prerequisite while making compost from weeds. Ideally, all weeds should be picked before they reach maturity and the seed bearing stage, but it is hardly practiced in practical. It has been established that temperature of about 55-60^0 Celsius should be produced in the compost to destroy the weed seeds. It was found that in NADEP method (when compost is made in above ground aerated pit made of bricks having holes), seeds of weeds like *Parthenium* and many grasses are not killed. Therefore, a pit method was developed and recommended to prepare the compost from weeds like *Parthenium* or grassy weeds (Sushillkumar *et al.* 2005). In this anaerobic method, seeds are completely killed due to rising of high temperature inside the pit. A pit of 3x6x10 ft (depth x width x length) may be prepared in field where water does not stagnate. The length and width of the pit may be reduced or increased but depth cannot be compromised. The bottom surface of pit should be compacted. The *Parthenium* biomass should be buried in the pit in layers. On each layer of 100 -150 kg, dung slurry (5 kg) and urea should (200 to-300 g) should be sprinkled. Many such layers can be formed and compacted till the pits is completely filled up to one feet above of ground surface. After filling the pit, it should be closed by the mixture of soil and dung. After 2- 4 months, depending upon the maturity of plants, we may get 37-35% compost from the initial *Parthenium* biomass filled in the pit. The compost prepared by *Parthenium* using additives like dung slurry and urea contained more nutrients than the compost prepared by open heap methods without additives or through dung only (Table 1).

Vermicompost making from weeds

Vermicomposting is an aspect of biotechnology involving the use of earthworms for recycling of non-toxic organic waste to the soil. Vermicomposting can easily be done from most of the terrestrial and aquatic weeds.Earthworm species most often used for composting are red wiggler (*Eisenia fetida* or *Eisenia andrei*); European night crawlers (*Eisenia hortensis*) and African night crawlers (*Eudrilus eugeniae*). Blueworms (*Perionyx excavatus*) may also be used in the tropics. Earthworms eat partially decomposed organic matter. Therefore, fresh weed biomass has to be partially decomposed and cooled before releasing the earthworm for converting the biomass into vermicompost. It was observed that *Parthenium* seeds remain viable even if passed from the guts of earthworms. Therefore, efforts have to be made to use such weeds for vermicomposting before flowering. Vermicompost can also be prepared from aquatic weed like water hyacinths, water fern and *Pistia* and *Ipomoea*. Aquatic weeds have high water content due to which they decomposed fast when kept in heap. No additional water is required for decomposing the aquatic weeds. Adding of dung slurry and turning hasten the process of decomposing of weed biomass. Two turning of heap are required at 20 days interval for aquatic weeds and 4-6 turning are required for terrestrial weeds for hasten the process of decomposing. As a thumb rule, cooled and partially decomposed weed biomass is best for offering o earthworms. If earthworms are released in hot decomposed biomass, they die.

CONCLUSIONS

Because of intensive farming system, the depletion of soil nutrients occurs to a greater degree leading to imbalance in availability of nutrients, loss of soil fertility and drastic reduction in crop productivity. Productivity of the soils cannot be sustained with the fertilizer alone. Organic manures must also form a part of farming to maintain the productivity of the soil. Farmers uproot and cut plenty of weed biomass from their crop fields during weeding process and such biomass are left generally on the bunds of the fields or thrown away outside from the field. This uprooted weed biomass may be converted into compost and vermicompost. Composting is the most widely applicable process of handling biodegradable organic wastes. Composting provides a way not only of reducing amount of waste that needs to be disposed of, but also of converting it in to a product that is useful for crop production. Weeds can be used for several purposes like anti-feedant, anti-repellent biogas production, paper and composite *etc*. But, all such methods requires skill and other essential equipment's; therefore these methods cannot be used by unskilled common man. However, weeds can be most effectively converted in compost and vermicompost without the need of costly equipment and money. It is one of the simplest way of utilizing the weeds.

Table 1. Nutrient analysis of compost of *Parthenium* prepared by conventional pit methods along with FYM and vermin-compost

Composting method	% value					
	N	P	K	Organic carbon	Ca	Mg
Open heap methodwithout additives	0.80	0.46	1.04	3.05	0.83	0.49
Pit method with additives	1.05	0.84	1.11	2.88	0.90	0.55
Vermicompost *Parthenium*	1.61	0.68	1.31	2.49	0.65	0.43
Dung compost	0.45	0.30	0.54	1.17	0.59	0.28

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Bio-prospecting the food potential of weedy relatives of crops: Studies with *Echinochloa* and *Physalis* species

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Human population is growing at an alarming pace and poses a threat to food and nutritional security, especially in developing countries. In countries, such as India, unpredictable climate and weather patterns lead to failure of major food crops frequently, including rice and wheat. Globally, almost 80% of our plant food supply comes from just 20 kinds of plants; hence, the sources of food lack diversification. Malnutrition, especially among the poor populations in India, or elsewhere, is another serious concern, as most of them survive mainly on core grains like wheat and rice. To tackle such problems, diversification of food is essential, to ensure availability and access to a variety of food types to poor people. Weedy relatives of some crops are a source of food that has hitherto been not adequately studied. There are many 'wild' species in the world, which have colonising abilities (i.e. weedy traits) and are suitable for human consumption. Exploring the opportunities for farming such species will help in providing better nutritional quality to poor populations. Increased domestication of weedy relatives of crop species may provide additional income from farming, as well as resilience to climate variability and scarcity of resources, such as water.

This study explored the above possibilities with two well-known 'weedy' species: i.e. *Echinochloa crusgalli* (Barnyard grass), *Physalis peruviana* (Cape gooseberry) and *Physalis minima* (Wild cherry). These species are known to display large variations in morphological traits, grow in relatively harsh conditions, and nutritionally high in value.

METHODOLOGY

***Echinochloa*:** A collection of about 118 accessions of *Echinochloa*, collected from different locations in India, was established initially as a nursery at Jabalpur, in plastic trays filled with a mixture of vermiculite, sand and soil (1:1:1). After 8 days, seedlings were transplanted in the field. Optimum cultural practices were adopted in cultivating the accessions, and observations were recorded at suitable growth stages. Variations in morphology, phenotypes, phenology, yield attributes, nutritional status, molecular diversity and phylogenetic relationship among accessions of *Echinochloa* were compared.

***Physalis*:** A collection of30 biotypes of *P. peruviana* and several of *P. minima* were obtained from different locations of India. Initially plants were grown in nursery. After 15 days, seedlings were transplanted in the field at Jabalpur with 1x1m spacing. Observations on morpho-physiological parameters, yield attributes, nutritional status, and molecular diversity were recorded.

RESULTS

Echinochloa

Data were recorded periodically on different morpho-pysiological characteristics. A high degree of variation was found among different accessions. Plant height varied from 61.2 to 151.6 cm at 45 days after transplanting (DAT). The variations in leaf area (57.7 to 1735.7 cm^2/plant) at 45 DAT, and number of panicles/plant (1.0 to 24.8) at 55 DAT, were both large. At 45 DAT, net photosynthesis varied between 12.88 and 36.37 µmoles/m^2/s. Similarly, variation was also observed in panicle length (5.03 to 22.44 cm) at 45 DAT. At maturity, seeds were harvested and seed yield (g/plant) and biological yield was recorded for each accession. Again, large variations were recorded in seed yields, which ranged from 0.49 to 9.60 g/plant, while the biological yield varied from 4.95 to 69.67 g/plant. Grains of 20 promising accessions, representing different biotypes of *Echinochloa* were analyzed for mineral contents (B, Fe, Mn, Zn, Ca, K, Mg, Na, P and S). The results revealed huge variations in mineral content among the different accessions. Transcriptomics analysis of a shattering-type and non-shattering type accessions of *Echinochloa* revealed significant differences in transcripts levels of numerous genes.

Table 1. Variations in different morpho-physiological characteristics among accessions of *Echinochloa*

Treatment	Photosynthesis µmoles/m^2/s)	Leaf area (cm^2)/plant	Root length (cm)	Panicles/ plant	Length of panicle (cm)	Grain yield (g/plant
	45 DAS	45 DAS	45 DAS	55 DAS	55 DAS	
Minimum	12.9	57.69	9.60	2.60	11.96	1.06
Maximum	36.4	1735.74	34.33	25.80	22.44	9.60
Mean	25.2	430.02	20.53	3.77	15.19	5.00
LSD (P=0.05)	0.67	53.02	2.64	0.89	1.38	0.893

Physalis

Observations on different parameters (photosynthesis, transpiration, shape, size colour and yield of fruits) were recorded. Results revealed variations in almost all the parameters studied. Variations in floral characters and pattern, reproductive parts and fruits have been evident in different species and biotypes of *Physalis* which may serve as an important key for identification as well as differentiation of these species. Molecular diversity analysis revealed large variations in different collections of *Physalis*. Fruits of four morphologically different biotypes of *Physalis* were analyzed for mineral contents (B, Fe, Mn, Zn, Ca, K, Mg, Na, P and S) and â-carotene. Acceptability of fruits at consumer end and richness in mineral content, such as Fe and Ca and â-carotene in *Physalis* fruits (as suggested by Puente et al. 2011) is of immense significance in fighting malnutrition in developing countries.

CONCLUSIONS

The results of the study suggest that *Echinochloa* and *Physalis* are the two species with 'weedy' traits, which are climate resilient, of high nutritional value, and potentially acceptable at consumers' end and profitable to the farmers to grow. Keeping in view these characteristics, both species are worthy of further consideration as 'future crops' for functional food for the poor, and as a component of climate-smart agriculture.

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Beautiful blue devil or Cinderella? Perspectives on opportunities with water hyacinth

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Much maligned as "The Beautiful Blue Devil", the floating aquatic plant - water hyacinth [*Eichhornia crassipes* (Mart.) Solms.] continues to be the regarded as the world's worst aquatic weed. However, paradoxically, information on the potential uses of water hyacinth is globally abundant, which appears to indicate that the plant's strengths can be further exploited. Historically, management of Water Hyacinth has relied on several control methods, including physical removal, herbicides and biological control agents. Each of these methods has its benefits and drawbacks. Utilization of water hyacinth is an alternative approach to control, as well as deriving an environmental and economic benefit from the plant's capacity to grow fast and produce large biomasses under favourable conditions. We suggest examining utilization options (reviewed in this paper) more closely as a workable approach, particularly in regions and countries where Water Hyacinth is native (i.e. South and Central Americas), and where it has become naturalized (i.e. South-Asia, including India, Bangladesh, Sri Lanka and Thailand). Utilization may not be an option in some countries, such as Australia, given the strengths of the species to aggressively invade waterways.

Water purification: In the USA, water hyacinth is highly valued in advanced wastewater treatment for water purification. Doubling its biomass every 7-18 days, water hyacinth can produce up to 2900 tonnes of fresh matter/ha/year (*ca*. 320 t dry matter/ha/year) depending on nutrient levels and a favourable climate (Thomas and Eden 1990). The potential for using water hyacinth for pollution removal from wastewater produced by many kinds of industries, including mining and groundwater contamination, is not yet fully realised.

Heavy metal phytoremediation: Water hyacinth efficiently absorbs dissolved impurities; in some cases, it acts as a 'hyper-accumulator' of heavy metals –lead, cadmium, nickel, arsenic, silver, etc and organic pollutants like phenols and dyes (Singhal and Rai 2003). Despite a wealth of impressive evidence, the benefits of water hyacinth's capacity for pollution removal have only been marginally exploited in many countries to date.

Production of biofuel: Given the capacity to produce a large biomass rapidly, water hyacinth is widely regarded as a useful source of bio-ethanol. In community bio-gas plants, to produce methane gas for domestic fuel, water hyacinth is a suitable substitute for cow dung. The slurry left can be used as organic manure.

Chemical products: Water hyacinth is a source of various natural products, including carbohydrates, proteins, amino acids, sterols and flavonoids. Compounds of high pharmaceutical and commercial value that are extracted from water hyacinth include: â-carotene; shikimic acid (lead compound for the vaccine Tamiflu®); and potentially, delphinidin, a well-known anti-cancer compound. The roots yield growth promoting gibberellins-like substances, diosgenin (pre-cursor of progesterone, in oral contraception pills) and stigmasterol.

Other uses: There are a multitude of other uses of water hyacinth. For instance, its fibre is widely used, either on the scale of cottage industries, or as medium-scale enterprises - to make paper, fibre board and other construction material, as well as ropes, baskets and the popular, decorative 'Water Hyacinth' furniture. Much evidence exists of other practical applications, such as mulch – to conserve water; fertilizer, and for soil amendment via composting. Similar uses, as food for farm animals, cattle, pigs and poultry, as well as fish food are plentiful from many countries.

DISCUSSION AND CONCLUSIONS

The paradox of a weed species being a liability, and a resource, is amply demonstrated by water hyacinth. The overwhelming evidence is that it is perhaps one of the most useful plants humans are interacting with. Yet, its exploitation for human welfare needs to be carefully managed and the benefits systematically harnessed. A change of attitude – from one of alienation to recognition of values of plants - will assist in sustainable utilization of the plant in beneficial ways, and may also lead to effective management of the weed, even with low-input technologies. Given that the techno-economic viability of many enterprises, based on water hyacinth is well proven, promotion of its practical use, where appropriate, is likely to increase in due course. We predict that this recognition will lead to a reversal our attitudes towards this extraordinary plant, and it may not be maligned for much longer, but respected as the "Cinderella" of the plant kingdom.

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Allelochemicals and natural products from weeds

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In weed management, allelopathy has three different approaches. One is allelopathy of weed as one of the detrimental effects of weeds on crops; and the other is the reciprocal effect - allelopathy of cropswhich can inhibit the growth of weeds. Utilization of allelopathic cover crop to inhibit the growth of weed is now distributing as an alternative way of weed control. Third field is to make new herbicides from allelochemicals. In this article, I provide an account of research that summarize the possibility of using allelochemicals from weeds and their applications in weed science.

Water quality improvement in wetland treatment system with emergent and free-floating weed species

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Among the most important sources of water pollution in urban environments are sewage from cities, drainage water from industries, such as waste water from dairies. It is estimated that more than 38,000 million litres of sewage water per day is generated, out of which only 35% is treated in India (CPCB 2009). Vegetables, grown as human animal food, are at risk due to the potential uptake of heavy metals in untreated wastewater which is often used for irrigation. Besides this, due to inadequate water treatment, wastewater carried long distances in open drains, which pass through cities and sub-urban villages, create unhygienic environments, affecting human and animal health. The abundance and survival of aggressive colonisers, such as *Arundo donax* L. (Giant Reed), *Typha latifolia* L. (Cattail) and *Eichhornia crassipes* (Mart.) Solms (Water hyacinth) in wastewater drains and associated contaminated sites and lagoons is testimony to such species having a capacity to accumulate urban pollutants within their plant parts.

The removal of heavy metals in wastewater by such macrophytes at source is easier than attempting to remove contaminants after they enter aquatic ecosystems. Emergent plants and free-floating macrophytes are both major components of constructed wetlands for water quality improvement. Constructed wetlands with free floating macrophytes consist of one or more shallow ponds in which plants float on the surface. The shallow depth and the presence of aquatic macrophytes in place of algae have better treatment performance as compared with stabilization ponds (Kedlec *et al.* 2000). Although the practice of using treatment ponds for water quality improvement in India is more than 25 years old, the performance of colonizing weed species for water treatment in constructed wetlands has not been adequately studied in sub-tropical parts of India.

METHODOLOGY

The two contaminated sites i.e. DWR point of Karonda drain and the Urdua village of Pariyet River, were selected for treatment of waste water. The performance of emergent weeds, *Arundo donax* and *Typha latifolia* was evaluated for heavy metal removal in constructed wetland at farm of Directorate of Weed Research, Jabalpur, India.

This constructed wetland system consisted of pre-treatment overhead settling tanks and two rows of treatment zone. Each row of treatment zone consisted of three tanks constructed in a sequence, first one as hydroponic followed by sub-surface-horizontal and surface-horizontal tank. Initially, *Arundo donax* (Giant Reed) was grown in both rows of treatment tanks. After two years of study, *Arundo* was replaced with *Typha latifolia* and *Vetiveria zizinoides* in separate rows of treatment zone. Floating weeds, *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* were tested for pollutant removal in pilot scale treatment system at Urdua village Jabalpur. The water samples from inlet and outlet of each tank of DWR and Urdua wetland were collected after 2 days and 5 days of hydraulic retention time (HRT) respectively. The heavy metals in water and plants were analyzed by Atomic absorption spectrophotometer (Thermo make, SOLAR-4).

RESULTS

The extensive root system of *Arundo* (110-134 cm in length) was developed in hydroponically grown tanks. The average density of plant was 172.3/m². As far as water flow through porous media filled tanks is concerned, no clogging occurs and water is discharged on irrigation plots through gravity flow. As compared with untreated drain water, the concentration of total soluble salts (TSS), nitrate, copper, nickel, zinc and manganese were reduced to the extent of 64.0, 88.4, 69.3, 62.4, 78.0 and 61.7%, respectively after 2 days of HRT. In a *Typha* treatment system, as compared with untreated drain water, 80.2 and 56.9% iron and copper were reduced in sub-surface tank after 2 days of HRT respectively. Higher cadmium of 26.3% was reduced by *Typha* in hydroponic tank which is than surface and sub-surface tanks (Table 1). In pilot scale system at Urdua, *E. crassipes* reduced chromium, turbidity and chloride to the extent of 76.2, 89.1 and 43% respectively which is higher than *Pistia stratiotes* (Table 2).

Table 1. Performance of *Typha* based wetland system for removal of heavy metals in drain water

Treatment	Fe (mg/L)	Fe removal Efficiency (%)	Cu (mg/L)	Cu removal Efficiency (%)	Cd (mg/L)	Cd removal Efficiency (%)
Overhead settling tank	0.224	31.6	0.0361	0.36	0.0101	19.7
Hydroponics	0.154	52.8	0.0286	21.0	0.0093	26.3
Sub surface tank	0.065	80.1	0.016	56.9	0.0106	15.7
Surface tank	0.035	89.1	0.0276	23.7	0.0106	15.7
Untreated drain	0.328	-	0.0363	-	0.0126	-

Table 2. Performance of *E. crassipes* in removal of pollutants in aquatic weed based water treatment system

Treatment	Turbidity (NTU)	Turbidity removal efficiency (%)	Cl (mg/L)	Cl removal efficiency (%)	Cr (mg/L)	Cr removal efficiency (%)
Overhead settling tank-1	58.6	8.5	52.4	1.13	0.33	5.7
Overhead settling tank-2	56.4	11.9	52.6	0.75	0.28	22.85
Treatment tank-1 (*P. stratiotes*)	20.4	68.1	50.6	4.53	0.10	61.87
Treatment tank-2 (*E. crassipes*)	6.9	89.1	30.2	43.01	0.08	76.25
Untreated drain	64.1	-	53	-	0.35	-

CONCLUSIONS

Emergent weeds (*Arundo donox* and *Typha latifolia*), grown in constructed wetlands, tolerated heavy metal concentrations round the year under the experimental conditions in sub-tropical climate of India. *Arundo* showed better performance for removal of copper, nickel, zinc, for development of plant consortia for control of pollution by aquatic weed based treatment system in small villages.

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Wetland colonizers to anti dandruff dermatitis – a scientific validation of indigenous technical knowledge on *Ipomoea*

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Most commonly known as chemical aspect of terrestrial science – allelopathy has its impact on aquatic ecosystems including wetlands. The pharmaceutical evaluation of the aquatic macrophytes is an emerging aspect of allelochemistry. In this context, is *Ipomoea aquatic* Forssk (Convolvulaceae), semi-aquatic, tropical plant grown as a vegetable and a key ecological community in wetland ecosystem has also been found to be immensely invasive in growth. Considering some ITK in north 24 parganas of West Bengal of the plant being good for hair white flakes removal in human, our current study aims to validate the knowledge by microbial screening against fungal dermatitis *Malassezia globosa* extracting crude leaf extract of *Ipomoea aquatica* which has been purified by liquid-liquid extraction process and further crystallized and each fraction subjected to biochemical analysis viz; phenols, flavonoids and tannins followed by selective antioxidant and antimicrobial activity. The inductive inferences of the various assays showed the ethanol fraction (80%) of the plant to be a natural resource to antidandruff compounds against *M. globosa*. A statistical approach to dose response curve is attempted for prediction of desired doses and results.

METHODOLOGY

The plant samples were collected from Akaipur beel in North 24 Parganas, West Bengal and subjected to laboratory processing. Following the preparative steps the leaves were shade dried and a homogenized powder was obtained which were soxhlet extracted with milipore water to ethanol in ascending ratios from 0, 20, 40 and 80% ethanol respectively. The amount of solvent added was in the ratio of 10:1 with respect to the dry weight of the plant. The set up was repeated in duplicate in triple repetitions. The crude extract were concentrated to dryness and subjected to the following biochemical analysis. The compound was tested for phenols, flavonoids, tannins. A simple TLC method initially followed by DPPH method and Fe^{2+} chelation method was used to evaluate the antioxidant property. Further experiments were accomplished with only the fourth fraction, *Ipomoea* ethanol fraction (IEF).

Antimicrobial assay was screened with *Malassezia globosa* with well diffusion assay using sabouraud dextrose agar with six different dilutions, viz. 1000, 500, 100, 50, 10, 1µg/ml including control with DMSO. After 24 hrs incubation, inhibition zones were obtained at 1000, 500 and 100 µg/ml. The MIC and MFC were performed by broth dilution assay using sabouraud dextrose broth with dilutions ranging from 10,000 µg/ml to 156 µg/ml by photometric method at 600 nm. MIC was recorded at 625 µg/ml while MFC at 2500 µg/ml conferred 99.5% killing fungicidal, which is in accordance to Arndt-Schulz rule.

RESULTS

In conclusion the present study finds that *Ipomoea aquatica* contains potential anti-dermatitis components that could be commercially utilized by pharmaceutical industries as a therapy as well scientifically validates the ITK.

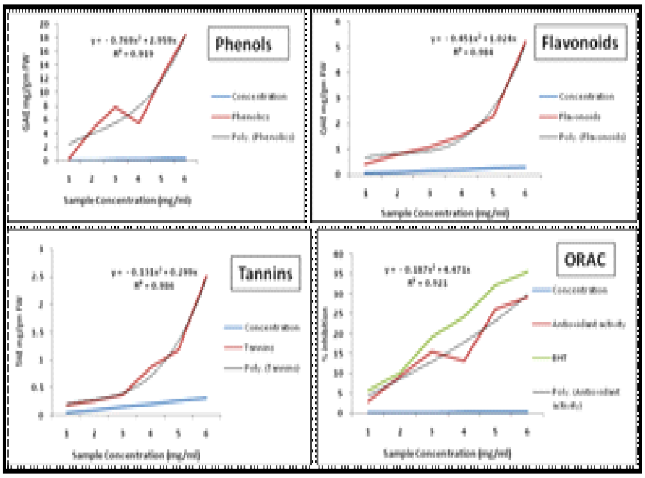

Fig. 1. Biochemical analysis of IE

Concentration (µg/ml)	OD 600
C1	0.506
156.2	0.383
312.5	0.372
625*	0.219
1250	0.081
2500	0.025
5000#	0.022
10,000	0.021
C2	0.016

Table 1. MIC* and MFC# of IE on *M. globosa*

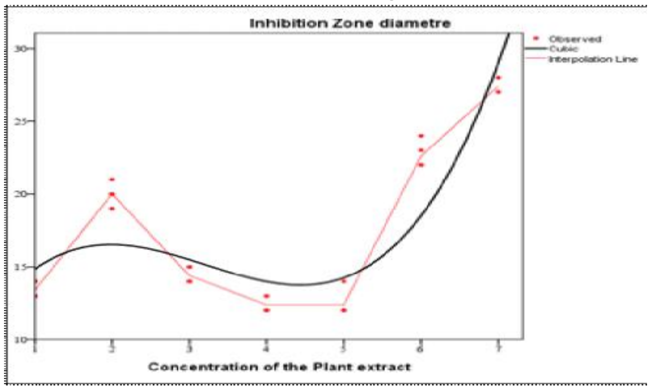

Fig. 3. Dose-response curve with cubic model, Eq: $y=8.229+9.828x-3.58x^2+0.372x^3$

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Technical Session 1

Weed management options for rice and rice based cropping systems of Asian-Pacific region

Effects of soil moisture conditions on emergence of weeds and rice in rainfed rice fields of lowland savanna of Ghana

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In order to establish an effective weed management system in rice fields in the flooded plains of tropical lowland savanna in Sub-Saharan Africa, information on dominant species and emergence ecology of weeds is indispensable (Morita *et al.* 2010). Changes in weed emergence caused by increase in soil moisture at the beginning of the rainy season are important information to determine the optimum sowing time of rice under rainfed conditions. Therefore, the effects of soil moisture on emergence of weeds and rice (*Oryza sativa* L.) plant were investigated using soils from rainfed rice fields of flooded plain in northern part of the Republic of Ghana. This study was conducted as a research project of Japan International Research Center for Agricultural Sciences (JIRCAS) under collaboration with Savanna Agricultural Research Institute (SARI), Ghana.

METHODOLOGY

Surface samples of heavy clay soil were collected on July 2013 at the beginning of rainy season and from inside and outside of experimental rice field (Inside and Outside Zaw) in farmer's field in Zaw Village ÿ 9°6'18" Nÿ1°9'21" E ÿ and two farmers' fields (Y1 and Y2) in Yipielgu Village ÿ9°22'32" Nÿ 0°5'9" E, both of which were located along White Volta river in northern Ghana. Four hundred gram of air dried soil filled in a polyethylene box of dimensions 125×172×65 mm, was adjusted into different soil moisture contents with tap water as 0, 10, 15, 20, 30 and 63% against soil weight. Ten seeds of Indica rice, cv. *"Sikamo"* and cv. *"Sakai"* were sown in the soil before moisture adjustment. Soil moisture was adjusted by measuring weight to supply tap water once a day. Emergence of broadleaf weeds, grasses and sedges, and rice plant were measured daily for 9 days. Experiment was conducted with three replications in a net house half-covered with vinyl film to protect from rain, at Savanna Agricultural Research Institute, Nyankpala in northern Ghana in middle September, 2013.

RESULTS

During the experiment, average air temperature during day/night was 30.2/24.8 ! and soil temperature was 30.4/24.7 !, respectively. *Paspalum scrobiculatum*, *Acroceras zizanioides* and *Digitaria* spp. were identified for seedlings of Gramineous weeds while identification was difficult for *Cyperus* and broad-leaved weeds. The greatest number of total emerged weed (broadleaf, grass and sedge) was obtained under 20% of soil moisture content (hereafter SMC), followed by 30% of SMC. Emergence of weed was hardly under 10% of SMC, and was suppressed remarkably under 15% of SMC and flooded condition (63%) throughout four soils examined.

Rice plants emerged most quickly under 20% of SMC, followed by 15% of SMC. Emergence of rice was suppressed remarkably under 10 and 30% of SMC and flooded conditions. Growth of rice seedling in leaf stage under 20% of SMC was significantly greater than these under other contents in soils of Zaw inside and Yipielgu-2, for both rice cultivars, "Sikamo" and "Sakai". Soil moisture content which would be enough for rice to emerge and avoid weed emergence was lower than that reported with sandy soil in rainfed paddy fields of north-eastern Thailand (Morita and Kabaki 2002).

CONCLUSION

Rice seedlings could emerge under 15% of SMC, while both weed and rice seedlings occurred vigorously under 20% of SMC. Sever weed emergence could be avoided, if seed paddy would be sown under 15% of soil moisture condition at the beginning of rainy season.

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Bio-efficacy of post-emergence new generation herbicides in transplanted rice

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Transplanted rice under lowland ecosystem is infested by heterogeneous weed flora which reduces the yield up to 48% and causes a yearly loss of 15 million tons of grain (Saha 2009). Among the various weed management techniques, chemical weed control is the better option due to low cost of cultivation. Hence a study was carried out to assess the bio-efficacy of post emergence herbicides in transplanted rice and to develop an economic weed management strategy.

METHODOLGY

The field investigation was carried out in a farmers' field in Kanjirathady Padashekharam in Kalliyoor Panchayath of Nemom Block, Thiruvananthapuram, Kerala during *Rabi* 2011. The soil was sandy clay, slightly acidic in reaction, medium in available N, K and high in P. The experiment was laid out in randomized block design with eight treatments *viz*., fenoxaprop-p-ethyl 60 and 90 g/ha, carfentrazone–ethyl 20 and 25 g/ha, fenoxaprop-p-ethyl 60 + carfentrazone-ethyl 20 g/ha, bispyribac-sodium 30 g/ha, hand weeding twice at 20 and 40 days after transplanting (DAT) and weedy check. '*Uma'* (M0 16), the medium-duration variety was used as the test crop. Twenty-four days old seedlings were transplanted at a spacing of 20 x 10 cm. The herbicides were sprayed on 20 DAT with a spray fluid of 500 l/ha. The crop was fertilized with 90 : 45 : 45 kg N : P_2O_5 : K_2O/ha. Data on weed growth and yield performance were recorded.

RESULTS

The weed flora was dominated by broad-leaf weeds (BLW), followed by sedges and grasses. The predominant species present were: *Limnocharis flava*, *Monochoria vaginalis* and *Ludwigia parviflora* among BLW, *Cyperus difformis* and *Fimbristylis dichotoma* among sedges and *Echinochloa colona* among grasses. The lowest weed density was observed in carfentrazone-ethyl at 20 g/ha which was on par with carfentrazone-ethyl at 25 g/ha and bispyribac-sodium at 30 g/ha. The total weed dry weight also followed the same trend. Wersal and Madsen (2012) reported that carfentrazone–ethyl was effective in reducing the dry matter accumulation in weeds. The WCE was highest in carfentrazone-ethyl at 20 g/ha closely followed by its higher dose 25 g/ha. Among the herbicides, the lowest WCE was recorded in fenoxaprop-p-ethyl which was owing to the fact that fenoxaprop-p-ethyl was less effective in controlling sedges and BLW. The highest yield (6.79 t/ha) was recorded in carfentrazone-ethyl at 25 g/ha which was on par with carfentrazone-ethyl at 20 g/ha (6.67 t/ha). The percentage increase in grain yield in carfentrazone-ethyl at 25, 20 g/ha and fenoxaprop-p-ethyl + carfentrazone-ethyl as compared to weedy check were 70.5, 67.7 and 60.7, respectively. The straw yield also followed the same trend. All the herbicide treatments recorded higher B: C ratio than hand weeding due to low cost of cultivation. The maximum net returns and B:C ratio were observed in carfentrazone-ethyl applied at 25 g/ha closely followed by its lower dose 20 g/ha.

Table 1. Effect of post-emergence herbicides on weed growth, WCE, yield and B:C ratio in transplanted rice (*Rabi* 2011)

Treatment	Total weed density 60 DAT (no/m^2)	Total weed dry weight 60 DAT (g/m^2)	WCE (%)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index	Net income (x10^3 `/ha)	B:C ratio
Fenoxaprop-p-ethyl 60 g/ha	92.0	68.0	42.5	4.96	7.56	28.5	33.09	1.50
Fenoxaprop-p-ethyl 90 g/ha	92.6	62.4	47.5	5.61	7.68	19.2	43.81	1.65
Carfentrazone-ethyl 20 g/ha	29.3	21.0	82.3	6.67	9.13	6.0	65.81	2.00
Carfentrazone-ethyl 25 g/ha	29.6	22.1	81.5	6.79	9.25	0.00	67.83	2.03
Fenoxaprop-p-ethyl 60 + carfentrazone–ethyl 20 g/ha	42.6	30.4	74.5	5.79	8.17	16.6	47.91	1.72
Bispyribac-sodium 30 g/ha	33.6	25.0	79.0	6.40	8.96	7.7	58.62	1.86
Hand weeding twice	52.3	45.3	61.8	6.11	8.77	11.9	38.49	1.46
Weedy check	161.3	119.4	-	3.98	6.83	42.6	17.17	1.27
CD (P=0.01)	11.3	9.9	NA	0.36	0.22			

CONCLUSION

Considering the weed control efficiency, yield and B:C ratio, application of new generation herbicide carfentrazone-ethyl at 20 g/ha on 20 DAT can be recommended for weed management in transplanted rice.

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Efficacy of herbicides and their combinations in managing complex weed flora of transplanted rice

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Rice is the main staple food in the Asia and the Pacific region, providing almost 39% of calories (Yaduraju and Rao 2013). In transplanted rice, uncontrolled weed growth caused 33-45% reduction in grain yield of rice in addition quality of grain is impaired (Manhas *et al.* 2012). Though many pre-emergence and post-emergence herbicides are available for controlling weeds, the complex weed flora in transplanted rice needs suitable combination of pre- and post-emergence herbicides to combat the weeds emerged during later stages of crop growth there by providing efficient weed management during critical period of crop-weed competition. Therefore, the present study was aimed to evaluate the efficacy of herbicides either alone or in combination for managing complex weed flora in transplanted rice to realize higher rice productivity and economic returns.

METHODOLOGY

A field experiment was conducted for four consecutive seasons during *Kharif* 2012, summer and *Kharif*, 2013 and summer 2014. Twelve treatments were replicated thrice in a RCBD design at Agricultural Research Station, Kathalagere, Davanagere District, Karnataka. The soil type was sandy clay loam with average fertility level. cv. 'JGL-1798' was sown at a common spacing of 20 cm x 10 cm and 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha were applied as per the recommendation. The gross and net plot sizes were 5.0 m x 3.0 m and 4.2 m x 2.6 m, respectively.

RESULTS

Major weed flora observed was *Cyperus difformis*, *Scirpus* sp. (from initial stages) *Fimbristylis miliacea* (from 60 days after transplanting {DAP} onwards) (among sedges), *Paspalum distichum*, *Echinochloa colona* (from initial stage) (among grasses). Major broad-leaved weeds were *Ludwigia parviflora*, *Rotala verticillaris*, *Monochoria vaginalis*, *Dopatrium junceum*, *Eclipta alba* (from initial stage), *Spilanthus acmella* (from 60 DAP). Among the weed species, the density of *Scirpus* sp, *C. difformis*, *E. colona*, *P. distichum*, *D. junceum* and *L. parviflora* were higher than other weed species, indicating their dominance from the beginning or at any stage of the crop cycle.

At 60 DAP, plots treated with pretilachlor 750 g/ha – 3 DAP *fb* ethoxysulfuron 18.75 g/ha – 25 DAP or chlorimuron-ethyl + metsulfuron-methyl 20 WP 4 g/ha – 25 DAP, pyrazosulfuron-ethyl 20 g/ha – 3 DAP fb manual weeding (45 DAP), bispyribac-sodium 25 g *fb* ethoxysulfuron 18.75 g/ha – 25 DAP or with chlorimuron- ethyl + metsulfuron- methyl 4 g/ha – 25 DAP gave lower total weeds density and dry weight (Table 1) comparable to hand weeding (25 and 45 DAP). The plots treated with pyrazosulfuron- ethyl 20 g/ha – 3 DAP *fb* manual weeding (45 DAP), pretilachlor 750 g – 3 DAP *fb* chlorimuron -ethyl + metsulfuron -methyl 20 WP 4 g ai/ha – 25 DAP or ethoxysulfuron 18.75 g/ha – 25 DAP gave paddy yields (6.12 to 6.41 t/ha) similar to or slightly better than two hand weeding (25 and 45 DAP) (6.20 t/ha) but significantly higher than other herbicide treatments. Unweeded control gave the lowest paddy yield (2.28 t/ha) owing to severe competition from weeds of all types as revealed from weed index (63.2%).

Table 1. Effect of herbicides and their combinations on total weed density (no./m^2) , total weed biomass (g/m^2)at 60 DAP, number of panicles / m^2, paddy yield (t/ha), weed index (%) and economics of transplanted rice at Kathalagere, UAS, Bangalore (pooled data of four seasons)

Treatment	Total weeds' density (no/m^2)	Total weed biomass (g/m^2)	Number of panicles /m^2	Grain yield (t/ha)	Weed Index (%)	Cost of weed management, (`/ha)	Savings in weeding cost, (`/ha over T11)
Bispyribac-sodium 10 SC 25 g – 25 DAP	1.75(55.3)	1.41(23.9)	265	4.71	24.1	2180	4320
Pretilachlor 1000 g – 3 DAP	1.85(68.5)	1.61(38.4)	256	4.59	26.0	1500	5000
Penoxsulam 22.5 g – 12 DAP	1.73(52.2)	1.37(21.7)	278	4.92	20.6	--	--
Pyrazosulfuron-ethyl 10 WP 20 g – 3 DAP	1.80(60.7)	1.51(30.3)	274	4.90	21.0	1125	5375
Bispyribac-sodium 10 SC 25 g + ethoxysulfuron 15 WG 18.75 g – 25 DAP	1.64(42.3)	1.07(9.7)	325	5.72	7.6	3368	3132
Bispyribac-sodium 25 g + chlorimuron-ethyl + metsulfuron -methyl 20 WP – 4 g 25 DAP	1.64(42.0)	1.06(9.6)	313	5.53	10.8	3030	3470
Pretilachlor 750 g – 3 DAP *fb* ethoxysulfuron 18.75 g – 25 DAP	1.50(29.9)	0.84(4.9)	353	6.12	1.3	2438	4062
Pretilachlor 750 g – 3 DAP *fb* chlorimuron-ethyl + metsulfuron-methyl 20 WP 4 g – 25 DAP	1.54(32.3)	0.90(5.9)	362	6.26	-1.0	2100	4400
Pyrazosulfuron-ethyl 20 g – 3 DAP *fb* manual weeding (45 DAP)	1.14(12.2)	0.50(1.2)	368	6.41	-3.4	4125	2375
Pretilachlor (6%) + bensulfuron (0.6%) 6.6% G 660 g – 3 DAP	1.75(54.3)	1.46(27.2)	313	5.48	11.6	2125	4375
Hand weeding (25 and 45 DAP)	1.18(13.1)	0.56(1.6)	357	6.20	0.0	6500	----
Weedy check	2.08(125.6)	1.90(81.3)	135	2.28	63.2	0	----
LSD(P=0.05)	0.14	0.11	28.2	0.46			

Herbicides or herbicide mixtures (`. 1125 to 4125/ha) were cheaper than hand weeding (` 6500/ha). The plots treated with pretilachlor 750 g – 3 DAP *fb* ethoxysulfuron 18.75 g/ha – 25 DAP or chlorimuron-ethyl + metsulfuron-methyl 20 WP 4 g/ha – 25 DAP, pyrazosulfuron- ethyl 20 g/ha – 3 DAP fb manual weeding (45 DAP) saved the weeding cost to an extent of ` 2375 to 4400/ha) as compared to hand weeding (25 and 45 DAP) (` 6500/ha).

CONCLUSION

Better weed control and economically higher rice productivity was obtained with pretilachlor 750 g – 3 DAP fb ethoxysulfuron 18.75 g/ha – 25 DAP or chlorimuron- ethyl + metsulfuron- methyl 20 WP 4 g/ha – 25 DAP and pyrazosulfuron- ethyl 20 g/ha – 3 DAP *fb* manual weeding (45 DAP). They were better than hand weeding and besides being economical, reduce the dependence on manual labour under present conditions of labour scarcity.

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Energy use and efficacy of weed management practices in aerobic rice

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In the present scenario of increasing water scarcity, aerobic rice is one of the contingent production systems. Weeds are one of the severest constraints to widespread adoption of aerobic, direct-seeded rice. The aerobic soil dry-tillage and alternate wetting and drying conditions are conducive to the germination and growth of weeds causing grain yield losses of 50-91**%.** Since the concept of aerobic rice is new, relatively limited information is available on the weed management practices and weed crop dynamics, which influence grain yield, energy use pattern in aerobic rice cultivation. It is necessary to develop suitable weed management practice to increase productivity and energy efficiency. With this background, a study was taken up to identify weed management practices that improve crop competitiveness against weeds by reducing weed biomass and increase grain yield and energy efficiency.

METHODOLOGY

The experiment was conducted in Randomized Block Design with three replications, with different weed management practices (pendimethalin *fb* bispyribac-sodium, pendimethalin *fb* 2,4-D Na-salt, pendimethalin *fb* ethoxysulfuron, pendimethalin *fb* chlorimuron + metsulfuron-methyl, butachlor *fb* bispyribac-sodium, butachlor *fb* 2,4-D-Na salt, butachlor *fb* ethoxysulfuron, butachlor *fb* chlorimuron + metsulfuron-methyl, mechanical weeding at 20 and 45 DAS, need based hand weeding and unweeded control. The experimental field was naturally infested with weeds such as *Echinochloa colona, Cyperus difformis, Cyperus iria, Eclipta alba, Ammania baccifera, Paspalum* spp. etc. For conversion of inventory into energy as is suggested by Nassiri and Singh (2009) were used.

RESULTS

The grassy weeds dominated the weed flora followed by broad leaf weeds (BLW). Most of the herbicides used in the study controlled BLW and grassy weeds to a large extent. Sedge population was low in the treatment of butachlor + 2,4-D Na salt application. Mechanical weeding recorded significantly higher BLW population (Table 1). The need based hand weeding recorded lowest weed biomass. Among the herbicides, pendimethelin *fb* bispyribac-sodium or chlorimuron + metsulfuron-methyl and butachlor fb bispyribac-sodium recorded significantly low weed biomass, low weed index, high weed control efficiency and high grain yield indicating the comparable effectiveness. The energy input was lowest in unweeded check followed by mechanical weeding treatment. The energy output and energy ratio were highest in need based hand weedings, followed by pendimethelin fb bispyribac-sodium treatment. The specific energy was higher with need based hand weeding and pendimethelin fb bispyribac-sodium, pendimethelin *fb* 2, 4-D Na salt.

Table 1. Weed parameters, Yield parameters and energy parameters in aerobic rice

Treatment	Grain Yield (t/ha)	Weed biomass (g/m^2)	Weed control efficiency	Energy input (MJ/ha))	Energy output (MJ/ha)	Energy ratio	Specific energy (MJ/Kg)
Pendimethalin 1.00 kg/ha(3-4 DAS) + Bispyribac-sodium 35 g/ha (15-20 DAS)	3.88	29.73	72.8	20,714	57,036	2.75	5.34
Pendimethalin1.00 kg/ha(3-4 DAS) +2,4 D-Na salt 0.06 kg/ha (20–25 DAS)	3.51	37.89	65.3	20,786	51,597	2.48	5.92
Pendimethalin 1.00 kg/ha (3-4 DAS) + ethoxysulfuron 15 g/ha (25-30 DAS)	3.41	38.50	64.7	20,845	50,127	2.40	6.11
Pendimethelin 1.00 kg/ha (3-4 DAS) + (chlorimuron + metsulfuron-methyl) 40 g/ha (25-30 DAS)	3.38	32.86	69.9	20,647	49,686	2.41	6.11
Butachlor 1.5 kg/ha (3-4DAS) + bispyribac-sodium 35 g/ha (15-20DAS)	3.76	32.19	70.5	20,714	55,270	2.67	5.51
Butachlor 1.5 kg/ha (3-4DAS) + 2,4-D,Na salt 0.06 kg/ha (20–25 DAS)	3.35	47.93	56.1	20,786	49,245	2.37	6.20
Pretilachlor 1.00 kg/ha (3-4 DAS) + ethoxysulfuron 15 g/ha (25-30 DAS)	3.33	48.21	55.8	20,845	48,951	2.35	6.26
Pretilachlor 1.00 kg/ha (3-4 DAS) + (chlorimuron + metsulfuron-methyl) 40 g/ha (25-30 DAS)	3.37	37.43	65.7	20,647	49,539	2.40	6.13
Mechanical weeding/weeders at 20 & 45 DAS	3.48	27.12	75.1	19,943	51,156	2.57	5.73
Need based hand weeding (4 at 15 day interval)	4.03	20.53	81.2	20,866	59,241	2.84	5.18
Unweeded	1.92	109.3	0	19,770	28,224	1.43	10.30
LSD (P=0.05)	0.28	4.89	NA	NA	NA	NA	NA

CONCLUSION

Sequential herbicide application of pendimethalin 1 kg/ha or butachlor 1.5 kg/ha 3-4 DAS); fb bispyribac-sodium 35 g at 2-4 leaf stage of mixed weed flora or chlorimuron + metsulfuron-methyl 40 g/ha at 25-30 DAS (for annual sedges and BLW) helps in realizing higher grain yields, higher energy output and energy ratio, that were comparable to or closer to need based hand weeding

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Integrated weed management in rice-rice cropping system under east and south-eastern coastal plain zone of Orissa

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Weeds pose a severe problem in reducing grain yield in rice-rice cropping system. The problem of weed infestation is particularly severe during *kharif* due to prevalence of congenial atmosphere for weed growth. Hand weeding is the most effective and common method to control weeds in this crop. However, scarcity and high cost of labour, particularly during peak period, and early crop-weed competition makes this operation difficult and uneconomic. Integrated weed management in rice-rice system can take care of weed infestation during early period of the crop growth and help to maintain satisfactory yield level of the crop. The present investigation was planned to study the effect of integrated weed management practices on weed dynamics, yield and economics of rice-rice cropping system in east and south-eastern coastal plain zone of Orissa.

METHODOLOGY

A field experiment was conducted consecutively for three years (2012-13 to 2014-15) in east and south eastern coastal plain zone of Orissa at Research Farm, OUAT, Bhubaneswar taking two farmers' practices as treatments in main plot for *kharif* rice (2 HW at 30 and 45 DAP, and pretilachlor 0.75 kg/ha at 3 DAP) and five weed control measures in sub-plots, for succeeding rice crop in rabi season [unweeded control, one HW at 40 DAP, 2,4-D EE 0.8 kg/ha (3 DAP), butachlor 1.25 kg/ha (3DAP) + almix 4 g/ha (3DAP), narrow spacing (15 x 10 cm) +1 HW (30 DAP)] in split-plot design replicated three times. Twenty-five days old seedlings were transplanted in July during *Kharif* and third week of January during *Rabi* in all the years taking '*Swarna*' and '*Lalat*' as test varieties during first and second season respectively. The crop was harvested during third week of November and second week of May in both the seasons respectively. Plant protection measures and irrigations were provided as and when required. The required quantity of herbicides were applied with manually operated knapsack sprayer using a spray volume of 500 litres water/ha.

RESULTS

The experimental plots were dominated by grasses like *Echinochloa colona, Panicum repens, Echinochloa crus-galli, Paspalum scorbiculatum, Leptochloa chinensis,* broad-leaf weeds like *Alteranthera sessilis, Ludwigia parviflora, Marsilea quadrifolia* and *Cynotis cuculata* and sedges like *Cyperus iria, Cyperus diformis* and *Fimbristylis miliacea* during *Kharif* season, whereas during Rabi season, the weeds were: *Echinochloa crus-galli, Echinochloa colona, Panicum repens* (among grasses), *Ludwigia parviflora, Marsilea quardifoliata (*among broad-leaf weeds), and *Cyperus iria* and C*yperus rotundus* (among sedges). Other weeds observed in lower densities were: *Paspalum scorbiculatum, Cynotis cuculata, Leptochloa chinensis, Fimbristylis miliacea, Alteranthera sessilis* and *Cyperus rotundus.* From the mean of three years it was observed that during *kharif* rice application of pretilachlor at 0.75 kg/ha (3 DAP) reduced weed density at 30 DAP (35.6/m^2), which was the critical period of crop weed competition although the practice of two hand weeding (farmers' practice) lowered the weed density (39.9/m^2) at harvest of crop (Table 1).

The pooled data of *rabi* rice indicated that weed control measures applied in *Kharif* rice (main plot) had significant effect on weed density of *rabi* rice at 30 DAP and at harvest. Application of pretilachlor 0.75 kg/ha (3 DAP) significantly reduced the weed density/m^2 (30.5 at 30 DAP and 50.7at harvest) as compared to farmers' practices. Among various herbicides applied in *rabi* rice, butachlor 1.25 kg/ha (3 DAP) + almix 0.8 kg/ha (3 DAP) recorded the lowest weed density of 11.3 /m^2 which was at par with 2,4-DEE 0.8 kg/ha (3 DAP) at 30 DAP, whereas at harvest narrow spacing (15 x 10 cm) + one HW (30 DAP) recorded lowest density (27.0/m^2) which was at par with one HW at 40 DAP(Table 1). At both the stages of observations unweeded check recorded significantly higher weed population than any other treatments (Table 1). During *Kharif* farmers' practice (2 HW at 30 and 45 DAP) recorded highest mean grain and straw yield of 4.77 and 5.51 t/ha respectively followed by application of pretilachlor 0.75 kg/ha(3 DAP). The highest yield of kharif rice with farmers' practice was associated with higher number of panicles/m^2 (375), grains/panicle (148), 1000-grain weight (23.7 g) and harvest

Table 1. Effect of weed control measures on weed dynamics, yield and yield attributes in rice-rice cropping system

Treatment	Weed density (no/m^{-2})		Weed biomass(g/m^2)		Panicles /m^2	Grains/ panicle	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index
	30 DAS	At harvest	30 DAS	At harvest						
Kharif rice(mean of three years)										
Farmers' practice (2 HW at 30 and 45 DAP)	72.7	39.9	30.9	20.3	378	148	23.7	4.77	5.51	46.4
Pretilachlor 0.75 kg/ha (3 DAP)	35.6	67.3	14.3	35.3	363	138	22.6	4.48	5.48	45.0
Rabi rice (pooled mean of three years)										
Weed management followed in *kharif* rice										
Farmers' practice (2 HW at 30 and 45 DAP)	34.4	54.1	21.1	26.4	270	135	21.8	3.54	4.36	44.8
Pretilachlor 0.75 kg/ha (3 DAP)	30.5	50.7	19.8	24.1	287	139	22.7	3.81	4.54	45.6
LSD (P=0.05)	1.34	1.55	0.23	1.10	9.66	NS	NS	NS	NS	-
Weed management followed in rabi rice										
Unweedy check	52.4	81.8	32.7	51.9	263	129	21.5	2.70	3.38	44.4
One HW (40 DAP)	50.9	29.5	32.5	16.3	294	145	22.9	4.16	5.17	44.6
2,4-DEE 0.8 kg/ha (3DAP)	11.7	34.8	4.6	21.1	279	140	22.3	3.79	4.71	44.6
Butachlor 1.25 kg/ha (3 DAP) + almix 4 g/ha (3 DAP)	11.3	33.0	4.3	19.2	285	139	22.5	4.10	5.16	44.3
Narrow spacing (15 x 10 cm) + 1 HW (30 DAP)	49.3	27.0	29.8	15.9	271	134	21.9	3.66	4.56	44.5
LSD (P=0.05)	2.34	3.63	1.07	0.66	7.05	5.78	0.56	0.26	0.32	-

index (46.4). It was observed from the pooled mean of Rabi rice that the grain and straw yield, 1000 grain weight and grains/ panicle were not significantly affected by weed management practices followed in *Kharif* rice. However, the maximum grain yield of 3.81 t/ha with highest HI (45.6) was obtained with the application of pretilachlor 0.75 kg/ha (3 DAP). Grain and straw yield, 1000-grain weight, number of grains/panicle and panicles/m^2 were significantly affected due to weed management practices followed in *rabi* rice. One hand weeding at 40 DAP recorded significantly higher grain yield (4.16 t/ha) followed by application of butachlor 1.25 kg/ha (3 DAP) + almix 4 g/ha (3DAP). The highest grain yield with one hand weeding at 40 DAP was associated with highest number of panicles/m^2 (294), grains/panicle (145), 1000 grain weight (22.9 g) and harvest index (44.6). The variation in grain yield under different treatments was the result of variation in weed density and biomass. The treatment which had more weed growth had low yield except with one HW at 40 DAP. These observations are in agreement with the findings of Singh and Singh (2001).

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Management of weeds in dry-seeded and aerobic rice systems

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Manual transplanting into puddled soils with continuous flooding is a most common practice of rice establishment in Asia. However, huge water inputs, labour costs and labour requirements for transplanted rice results in reduction of profit margins (Chauhan *et al.* 2013). The rising labor cost, water shortage and the need to intensify rice production through double and triple cropping provide the economic incentives for a switch to direct seeding. The sustainability of direct-seeded rice systems, however, is threatened by heavy weed infestation (Mahajan and Chauhan 2013). Weed control is particularly challenging in these systems because of diversity of weeds and the severity of infestation; absence of standing water to suppress weeds at the time of crop emergence; alternate wetting and drying conditions; and the absence of a seedling-size advantage between rice and weed seedlings, as both emerge simultaneously, causing grain yield losses of 50–91% (Rao *et al.* 2007). Use of low-dose high-efficacy post-emergent herbicides/ herbicide mixtures having broad spectrum of weed control are expected to be an intervention to suppress the weeds in direct-seeded rice. The present investigation was undertaken to study the weed spectrum and the efficacy of different herbicides/ herbicide mixtures in dry-and aerobic rice grown under different establishment methods.

METHODOLOGY

The experiment on dry-seeded rice (cv. '*Pooja*') was carried out during the wet seasons of 2013 and 2014 at the Institute Farm. Three rice seeding methods viz., broadcast seeding, continuous seeding at 15 cm apart rows, and sowing by a seed drill, in main plots and five weed control treatments viz., bispyribac-sodium (30 g/ha), azimsulfuron (35 g/ha) and bensulfuron methyl+pretilachlor at 70+700 g/ha along with hand weeding (twice) and weedy as check, in subplots were evaluated in a split plot design with three replications. Another experiment on irrigated aerobic rice (cv. 'Pyari') was laid out in a split plot design with three rice seeding methods [broadcast seeding, continuous seeding at 15-cm apart rows, and spot seeding at 15 cm x 15 cm spacing] in main plots and five weed control treatments [weed-free, weedy check, bispyribac-sodium (30 g/ha), azimsulfuron (35 g/ha) and flucetosulfuron (25 g/ha)] in subplots during dry seasons of 2012 and 2013. The data collected on weed density, weed biomass, yield parameters, etc., were analyzed using ANOVA.

RESULTS

In dry-seeded rice, *Echinochloa colona* was the most predominant weed species in weedy plots followed by *Cyperus iria* and *Ludwigia octovalvis*. The grassy weeds constituted 54% of the total weed population in weedy plots followed by sedges (25%) and broadleaved weeds (21%). Weed infestation was comparatively less in plots where rice was seeded by the seed drill (weed biomass 22.3 g/m^2 at 60 days after sowing) resulting in better rice growth and highest grain yield (4.59 t/ha). Among the herbicide treatments, higher weed control efficiency (91%) and rice grain yield (4.88 t/ha) was recorded with azimsulfuron-treatment, which was comparable with hand weeding twice (5.01 t/ha). Drill-seeding of rice recorded 19% higher yield over rice broad-cast seeding. The rice yield reduction in weedy plot was 51%.

In aerobic rice, the major weed species in weedy plots were *Echinochloa colona*, *Cyperus difformis*, *Fimbristylis miliacea*, *Sphenoclea zeylanica*, *Leptochloa chinensis*, *Alternanthera sessilis* and *Cleome viscosa*. Among herbicide treatments, the lowest weed biomass (8.2 g/m^2 at 60 days after sowing) was recorded in the azimsulfuron-treated plots with the WCE of 89%. Among different crop establishment methods, the lowest weed biomass (26.8 g/m^2 at 60 days after sowing) was recorded in the spot-seeded plots due to better crop establishment. Application of azimsulfuron produced highest yield (4.31 t/ha), among different herbicide treated plots, when rice was established by spot seeding. Spot-seeded rice produced 23% higher yield over broad-cast seeding due to better crop growth which helped in better weed suppression (Mahajan and Chauhan 2013). The yield reduction in weedy plot was 59%.

CONCLUSION

Drill-seeding of rice provided resulted in better establishment of dry-seeded rice during wet seasons, while spot-seeding provided better crop establishment under aerobic condition during dry seasons. In both the systems, post-emergent application of azimsulfuron at 18-20 days after sowing (3-4 leaf stage of weeds) provides broad spectrum of weed control in comparison to early application of post emergent herbicides/herbicide mixtures (bispyribac sodium, flucetosulfuron and bensulfuron methyl + pretilachlor) at 7-10 days after sowing.

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Weed shift, soil health and crop productivity in rice (autumn) - rice (winter) sequence in relation to long term herbicide use

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Rice-rice cropping system is one of the major cropping systems of Eastern and Southern India. Weed management is one of the major considerations for realizing higher productivity. Farmers are generally applying same herbicide season after season. Moreover, application of only fertilizers as nutrient sources is also resulting soil fatigue. Thus, it is also very much important to monitor the long-term effect of weed control practices as well as integrated nutrient management on crop productivity, soil health as well as changes in weed flora.

METHODOLOGY

A long term trial was initiated during 2001-02 on autumn rice- winter rice sequence at the ICR farm, Assam Agricultural University, Jorhat to evaluate the long term effect of repeated or rotational application herbicide on weed growth, crop productivity, soil health and weed shift. The experiment comprised of five treatments *viz.* Farmers' practice (one hand weeding), Butachlor 1.5kg/ha +2,4-D 0.75kg/ha (100% NPK through fertilizer), Butachlor 1.5kg/ha+2,4-D 0.75kg/ha (75% NPK through fertilizer+ 25% NPK through organic source), Butachlor 1.5kg/ha +2,4-D 0.75kg/ha rotated with pretilachlor 0.75 kg/ha (100% NPK through fertilizer) and Butachlor 1.5kg/ha +2,4-D 0.75kg/ha rotated with pretilachlor 0.75 kg/ha (75% NPK through fertilizer+ 25% NPK through organic source. The varieties 'Luit' and 'Ranjit' were grown as autumn and winter rice, respectively. The pre- emergence herbicides *viz.* Butachlor and Pretilachlor as per treatment were applied after mixing with sand. The post emergence herbicide 2,4-D was applied as per treatment during active vegetative stage of the crop. Nutrients at recommended doses were applied through chemical fertilizers and organic source farm yard manure (FYM) calculating the proportions as per treatment.

RESULTS

Weed species diversity more particularly broad leaved grasses in autumn rice and grasses in winter rice were greatly reduced due to continuous herbicide application. Initially, the major weed flora in autumn rice consisted of *Monochoria vaginalis*, *Sacciolepsis interrupta, Cyperus iria* and *Eleocharis dulsis* while during the winter rice, the predominant species were *Monochoria vaginalis*, *Sacciolepsis interrupta, Hydrolea zeylanica* and *Eleocharis dulcis.* Grasses were successfully reduced by continuous application of butachlor alone or butachlor rotated with pretilachlor. Similar trend was also reported by Chinnusamy *et al.* (2012). After 13 years, dominant species were submerged-suspended weeds belonging to *Ceraphylum-Utricularia* complex, *Monochoria vaginalis, Sphenoclea zeylanica, Eleocharis acutangula, Scirpus juncoides* and *S. maritimus.* Perennial tuberous aquatic sedge *Eleocharis dulcis* was drastically reduced by the herbicide application. Since 2012, there was no appearance of grass like *Isachne himalaica*, sedges like *Fimbristylis littoralis* and C*yperus iria* and broad leaved like *Ipomoea aquatica* and *Sagittaria guayanensis*.

There was an increase in the weed density over the initial year of 2001 and it was more in winter rice. However, herbicide treatments checked its buildup as compared to farmers' practice. Rotational use of herbicide resulted decreased weed density. Marginal increase in dry weight of weeds was observed up to 2009 but it increased remarkably in 2013 as compared to 2001.Grain yield of both autumn and winter rice decreased till 2005 and remained at a stable level thereafter. All the herbicide treatments were superior to farmers' practice from 2005. Herbicide rotation produced higher grain yield as compared to use of same herbicide. Duary *et al.* (2012) also reported similar benefit from rotational use of herbicide.

Fertilizer substitution (25%) with FYM improved nutrient status of surface (0-15 cm) and subsurface (15-30 cm) layers of soil irrespective of herbicides. Herbicide application along 25% fertilizer substitution with FYM resulted lower bulk density and higher organic carbon in soil. In the treatments receiving organic manure, population of bacteria was comparatively higher than those receiving only chemical fertilizers in 2005 but fungal population did not show any difference. However during 2013, the population of both bacteria and fungus were higher with herbicidal treatments than farmers' practice.

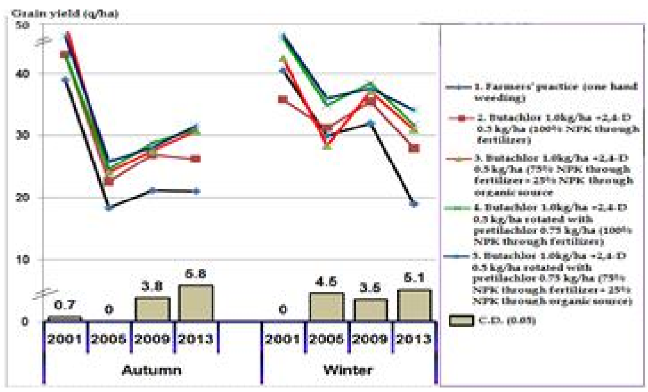

Fig. 1. Grain yield variation of autumn and winter rice due to weed management treatments during 2001-13

CONCLUSION

Rotational use of butachlor and pretilachlor in autumn rice-winter sequence along with 25 % substitution of fertilizer with FYM resulted effective control of weeds, higher grain yield and maintenance of soil health.

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Weed management in upland rice for productivity enhancement under hill ecosystem of north-east India

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Weeds are major constraints in upland rice eco-system and weeds reduce rice productivity to the extent of 98% (Oerke and Dehne 2004). Escalating labour wages, lack of timely availability of labour often limits timely weed control resulting in poor crop productivity. Herbicides are now recognized as one of the efficient and economic method of weed control. Pre-emergence herbicides alone often fail to provide satisfactory weed control as weeds emerge in several flushes. Accordingly, sequential application of pre and post emergence herbicides may provide efficient weed control in upland rice. Evaluation of appropriate weed control practices for upland rice in hill ecosystem is essential for realizing higher rice productivity; hence the present investigation was undertaken.

METHODOLOGY

A field experiment was conducted during *kharif* 2013 and 2014 at ICAR Research Complex, Umiam (Meghalaya). Seven treatments (Table 1) consisting of different herbicide combinations and mechanical weeding treatments arranged in randomized block design with three replications. The herbicides as per treatment were applied with knapsack sprayer fitted with flat fan nuzzle with a spray volume of 450 l/ ha. The crop received a recommended dose of 60:40:40 kg/ha applied through urea, single super phosphate and muriate of potash. One third of recommended nitrogen and full dose of P_2O_5 and K_2O fertilizers were applied as basal and remaining nitrogen was applied in two splits viz., at maximum tillering and panicle initiation stages. The rice variety "*Bhalum 1*" was sown at 20 cm spacing. Weed density and biomass were recorded at 60 days after seeding (DAS).

RESULTS

The weed flora consisted of grasses (66%), broadleaf (22%) and sedges (12%).Weed control practices exerted significant influence on weed growth and yield of rice during both the years of study. All the weed control practices significantly reduced the weed density and biomass. Unweeded control resulted in maximum weed density and biomass resulting in complete crop failure. Significantly higher rice grain yield (4.26 and 5.10 t/ha, during 2013 and 2014, respectively) was recorded with the application of cyhalofop-butyl 80 g/ ha at 25 DAS followed by 2, 4-D 0.75 kg/ ha at 35 DAS (5.10 t/ha) followed by pre-emergence application of butachlor 1.5 kg/ha followed by 2,4-D 0.75 kg/ ha..

Table1. Effect of different weed control treatments on associated weeds growth and yield of upland rice

Treatment	Weed density (no/m^2) 60 DAS		Weed biomass (g/m^2) 60 DAS		Grain yield (t/ ha)		Straw yield (t/ ha)		WCE (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Weedy check	471^{a}	555^{a}	311.5^{a}	274.9^{a}	0.0^{d}	0^{f}	0.0^{c}	0^{e}	-	-
Cyhalofop-butyl 80 g/ ha (25 DAS) *fb* 2, 4D 0.75 kg/ ha (35 DAS)	195^{b}	128^{c}	$71.1b^{c}$	31.2^{b}	4.26^{a}	5.10^{a}	6.76^{a}	7.08^{a}	77.1	88.6
Butachlor 1.5 kg/ ha *fb* 2,4D 0.75 kg/ha (25 DAS)	160^{b}	124^{c}	$87.1b^{c}$	33.2^{b}	3.70^{abc}	4.60^{b}	6.73^{a}	6.97^{a}	72.0	87.9
Mechanical weeding (Grubber) at 20 and 40 DAS	211^{b}	145^{b}	127.9^{b}	45.1^{b}	3.76^{abc}	4.33^{c}	5.95^{ab}	6.60^{b}	58.9	83.4
Pretilachlor 0.75 kg/ ha *fb* 2, 4-D 0.75 kg/ ha (25 DAS)	171^{b}	97^{e}	55.3^{c}	44.7^{b}	3.30^{c}	4.10^{d}	5.16^{b}	6.17^{c}	82.2	83.7
Fenoxaprop 60 g/ ha (15 DAS) *fb* 2,4D 0.75 kg/ ha (25 DAS)	175^{b}	111^{d}	55.9^{c}	34.0^{b}	3.36^{bc}	3.70^{e}	6.46^{ab}	5.49^{d}	82.0	87.6
Weed-free up to 60 DAS	0^{c}	0^{f}	0^{d}	0^{c}	4.10^{ab}	4.46^{c}	6.70^{a}	5.60^{d}	85.0	88.3

CONCLUSION

Post-emergence application of cyhalofop-butyl 80 g/ ha (25 DAS) followed by 2,4-D 0.75 kg /ha (35 DAS) was most effective for managing weeds and improving upland rice productivity under hilly ecosystem of Meghalaya.

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Herbicide combinations for management of complex weed flora in wet-seeded rice of Telangana State

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In the last five years the cost of production on different operations is increased by 33% on seed, 45% on fertilizers, 100% on labour wages, 35-40% on tillage operations making the cultivation of rice unprofitable (Rao *et* al. 2013). Under these circumstances, rice production systems are undergoing several changes and one of such changes is shift from transplanted rice to direct seeding. But sprouted rice seed on puddle soil is confronted with problem of profuse growth of weeds. Weed competition reduced the grain yield by 50-60% in direct-seeded low land rice.

METHODOLOGY

The study was carried out at college farm, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Rajendranagar, Hyderabad situated at an altitude of 542.3 m above mean sea level at 17°19' N latitude and 78°23' E longitude. The experiment was laid out in CRD with 3 replications having 11 treatments. The sprouted seed of rice var. '*MTU 1010'* was sown in well puddled soil. The recommended fertilizer dose of 150-60-40 kg NPK/ha was applied as per the recommendation. Data on weeds and yield of the drum- seeded rice was recorded 120 days after seeding (DAS).

RESULTS

Weeds observed during crop growing season were *Cyperus difformis*, *Eclipta alba*, *Echinocloa colona*, *Echinochloa crusgalli* and *Paspalum distichum. The lowest weed density was noticed* with pyrazosulfuron-ethyl *fb* HW at 40DAS and was on par with weed free treatment, which in turn was on par with early post emergence application of bispyribac sodium *fb* HW (40 DAS). The lowest weed biomass was recorded with weed free treatment and was on par with pyrazosulfuron-ethyl *fb* HW at 40DAS, early post emergence application of bispyribac-sodium *fb* HW (40 DAS) and pretilachlor +safener *fb* azimsulfuron. Significantly the highest weed density and weed dry matter biomass was recorded with weedy check. *Significant increase in grain and straw yield was noticed with weed free treatment (*3.78 and 5.33 t/ha) and was on par with pyrazosulfuron-ethyl *fb* hand weeding at 40 DAS, bispyribac -sodium *fb* HW (40 DAS), pyrazosulfuron-ethyl *fb* azimsulfuron (25-30 DAS) and pretilachlor + safener *fb* azimsulfuron (25-30 DAS) respectively. Similar trend was reflected with weed control efficiency also. The lowest weed index values were also observed with above treatments. The yield loss due to uncontrolled growth of weeds as compared to hand weeding was 79%.

Table 1. Weed growth, yield and economics of rice as influenced by different weed control treatments

Treatment	Weed density (no/m^2)	Weed biomass (g/m^2)	WCE (%)	Weed index (%)	Straw yield (t/ha)	Grain yield (t/ha)	Cost of cultivation (x10^3/ha)	BC ratio
Azimsulfuron 35 g/ha (25-30 DAS)	6.60 (42.6)	12.17 (147.3)	16.6	41.0	3.72	2.22	35.32	0.88
Pretilachlor 450 g/ha + safener *fb* HW (40 DAS)	7.46 (54.6)	8.69 (74.67)	57.7	23.2	4.45	2.90	34.94	1.16
Pretilachlor + safener 450 g/ha *fb* azimsulfuron 35 g/ha (25-30 DAS)	5.35 (28.0)	6.55 (42.0)	76.2	13.5	4.98	3.26	37.267	1.23
Bensulfuron methyl + pretilachlor 60 + 600 g/ha *fb* HW (40 DAS)	5.08 (25.0)	7.72 (58.6)	66.7	31.9	4.45	2.57	39.38	0.92
Bispyribac sodium 25 g/ha *fb* HW (40 DAS)	4.12 (16.0)	6.43 (40.6)	76.9	10.4	5.03	3.38	39.03	1.21
Pyrazosulfuron-ethyl 20 g/ha *fb* HW (40 DAS)	2.95 (8.0)	6.34 (39.3)	77.7	5.2	5.05	3.48	37.80	1.29
Oxadiargyl 80 g/ha *fb* HW (40 DAS)	6.69 (44.0)	8.53 (72.0)	59.2	56.0	3.18	1.66	37.68	0.62
Pyrazosulfuron-ethyl 20 g/ha *fb* azimsulfuron 35 g/ha (25-30 DAS)	5.62 (30.7)	8.34 (68.6)	61.1	12.8	4.59	3.29	36.13	1.28
Oxadiargyl 80 g/ha *fb* azimsulfuron 35 g/ha (25-30 DAS)	5.25 (26.7)	10.88 (117.3)	33.5	46.4	3.02	2.02	36.01	0.79
Weed free (hand weeding at 20 and 40DAS)	3.73 (13.3)	6.29 (38.6)	78.1	0.0	5.33	3.78	41.00	1.29
Weedy check	7.08 (49.3)	13.32 (176.6)	0.0	79.1	2.70	0.78	33.00	0.33
LSD (P=0.05)	0.96	0.91	-	-	0.86	0.52	-	-

*Values in parentheses are original. Data transformed to square root transformation

CONCLUSION

Under labour scarce conditions, either pre-emergence application of pyrazosulfuron-ethyl 20 g/ha at 8-10 DAS *fb* manual weeding at 40 DAS or pyrazosulfuron-ethyl 20 g/ha at 8-10 DAS *fb* azimsulfuron 35g/ha at 25-30 DAS was found to be effective to get higher wet-seeded rice yield (3.48 and 3.29 t/ha) and benefit cost ratio (1.29 and 1.28).

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Weed suppression ability of two rice varieties under aerobic conditions

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Weeds have been a major biotic constraint in aerobic rice system of rice cultivation due to: 1) wide diversity in weed flora, 2) simultaneous germination of rice and weeds, and 3) conducive aerobic conditions for weed growth. The extent of yield loss due to weeds varies from 50-100% depending on the cultural methods, rice cultivars and associated weed species density and duration of competition. Although herbicides have been the economical method of weed control, the degree of weed control achieved by herbicides may vary with rice cultivar as genetic variation in their competitive ability against weeds exist. Enhancing crop competitiveness against weeds could reduce weed control costs by 30% (Sanint *et al.* 1998) and its harnessing can be important for weed management in aerobic rice.

METHODOLOGY

A field experiment was conducted during the summer 2012 and 2013 at Punjab Agricultural University, Ludhiana, India. The experiment was laid out in a split-plot design with two cultivars (*'PR 114'*, of 145 days (d) duration; and *'PR 115'*, of 125 d duration) as main plots treatments and 12 weed control timings [weedy and weed free conditions, each of which, maintained until 14, 28, 42, 56, and 70 days after sowing (DAS) and until crop harvest] as the sub-plots treatments. Rice at 25 kg/ha was sown with seed-drill in 20-cm wide rows. The field was irrigated immediately after sowing and was kept moist throughout the season Weeds were removed by hand hoeing as per the treatments. Weeds in the weedy plots were kept for different periods as per the treatment and were sampled at the time of weed removal., In the plots that were kept weed-free for different periods, weeds sampling was done at harvest. Weed biomass data was pooled over the years and square-root transformed for statistical analysis and actual biomass values are presented for clarity. The GLM procedure in SAS 9.3 was used to evaluate the statistical differences among treatments at P=0.05.

RESULTS

Biomass of all the weed types was dependent on the weedy duration in the crop. For the initial weedy duration, the weed biomass increased with the time of weedy duration in rice, while for the initial weed free duration, the weed biomass decreased with the delayed period of allowing weeds to emerge. Grasses and sedges were dominant weeds in this study. Grass weed biomass was same with both varieties for initial 42 days, in weedy or weed free conditions. At 56 days of rice seeding (DAS), greater grass weeds biomass was with 'PR 115' than with 'PR 114' and under weed free conditions also weed biomass was comparatively lesser with 'PR 115' (30 g/m^2) over 'PR 114' (50 g/m^2) at 56 DAS. Sedges biomass was same in both the varieties when kept weedy up to 28 DAS and beyond 28 DAS of initial weed free period. At 42 and 56 DAS, sedges biomass was less by 23.6 and 22.6%, respectively in association with 'PR 115' as compared to 'PR 114'. Similarly, under weedy conditions, lesser sedges biomass (16.8 and 20.3%) was recorded with PR 115 than with 'PR 114' up to harvest and initial weed free period of 14 days. Beyond 14 days of weed free maintenance showed similar competitive ability by both the varieties. Varietal difference was not observed in their competitive ability against broadleaved weeds, probably because of the lesser biomass of broadleaf weeds. Total weed biomass was lesser in association with 'PR 115' (244 g/m^2) as compared to 'PR 114' (291 g/m^2) at 42 days of initial weedy conditions. Under initial weed free period of 14 days and at weedy conditions, weed biomass was reduced by 13.5 and 8.8% under 'PR 115' at harvest.

CONCLUSION

This study indicated higher weed competitive ability, especially against sedges of 'PR 115' than 'PR 114'. However, for grasses, such difference in weed suppression among the varieties was observed when plots were kept weed free up to 56 DAS.

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Bioefficacy of sequential application of herbicides in rice-rice cropping system on farmers' fields in Telangana State

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Rice, a major crop of Telangana State grown in an area of 16.5 lakh ha, suffers badly due to infestation of wide variety of weeds. Unchecked weed competition causes yield losses up to 65% in rice (Subbaiah and Sreedevi 2000). Though the conventional method of manual weeding is widely practiced, herbicides are in high demand due to shortage of labour and escalating wages. Farmers are using pre-emergence herbicides like pretilachlor and oxadiargyl in rice. However, the continuous use of a single herbicide or herbicides having the same mode of action may lead to the resistance problem in weeds. Of late, herbicide formulations with high efficacy, herbicide mixtures and herbicides with safner are showing better results (Moorthy and Saha 2002). Pre-emergence application of pretilachlor + two hand weddings at 25 and 45 DAT was found to give effective weed control with greater reduction in density and dry weight of weeds in rice (Subramanian *et al*. 2006). Combination of pre- and post-emergence herbicides is essential in rice. Awareness on the use of post emergence herbicides in rice is lacking among the farmers. Hence, the present investigation was undertaken.

METHODOLOGY

A field experiment was carried out during *Kharif* and *Rabi* seasons of 2010-11 in 16 farmers' field spread across Warangal district, Telangana State to study the efficacy of sequential application of pre-and post-emergence herbicides in rice-rice cropping system. Five treatments were pretilachlor (50 % EC) 0.625 kg/ha at 5 days after transplanting (DAT) as pre-emergence (PE); oxadiargyl (80% WP) 100 g/ha at 5 DAT as PE; pretilachlor 0.625 kg/ha at 5 DAT followed by (*fb*) bispyribac-sodium (10 % EC) at 20 g/ha at 15-20 DAT as post-emergence application (POE) and oxadiargyl at 100 g/ha at 5 DAT fb 2,4 -D Na salt (80 WP) at 0.8 kg/ha at 15-20 DAT as POE along with the weedy check. Each farmer's field constituted a separate replication, thus tested in a randomized block design. The plot size was 10 x 10 m. Most popular rice varieties in the region i.e., *'BPT 5204'* during *Kharif* and *'MTU 1010'* during R*abi* season, respectively were raised under transplanted conditions with all the package of practices recommended for the agro-climatic zone. Data on weed count, weed dry matter and yield performance were recorded.

RESULTS

Herbicides significantly influenced the weed dry matter, weed control efficiency and yield of rice during both the seasons (Table 1). The sequential application of oxadiargyl 100 g/ha at 5 DAT *fb* 2, 4-D Na salt 0.8 kg/ha 15-20 DAT and pretilachlor at 0.625 kg/ha at 5 DAT fb bispyribac-sodium 100 g/ha at 15-20 DAT significantly reduced the dry matter of weeds as compared to all the other herbicide treatments including pre-emergence herbicides. Weed control efficiency and grain yield of rice was also higher with the sequential application of pretilachlor 0.625 kg/ha fb bispyribac-sodium 20 g/ha and oxadiargyl 100 g/ha *fb* 2,4-D Na salt 0.8 kg/ha as compared to all the other treatments. These results are in conformity with the findings of Moorthy and Saha (2002).

Table 1.Weed dry matter, weed control efficiency and yield of rice as influenced by sequential application of herbicides

Treatment	Weed dry matter at 40 DAT* (g/m^2)		Weed control efficiency at 40 DAT (%)		Grain yield (t/ha)		Straw yield (t/ha)	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Pretilachlor	10.98	6.78	48	32	4.26	2.90	5.44	3.88
Oxadiargyl	10.12	6.14	61	44	4.41	3.46	5.66	4.41
Pretilachlor *fb* bispyribac-Na	8.59	4.87	72	66	4.72	4.32	5.92	5.29
Oxadiargyl *fb* 2,4-D Na salt	7.18	4.10	77	76	4.77	3.91	5.84	4.91
Weedy check	13.65	8.26	-	-	2.86	1.87	3.53	2.86
LSD (P=0.05)	0.42	0.63	-	-	0.14	0.25	0.27	0.29

*Data transformed to square root transformation

CONCLUSION

Sequential application of oxadiargyl 100 g/ha *fb* 2,4-D-Na salt 0.8 kg/ha or pretilachlor 0.625 kg/ha at 5 DAT *fb* bispyribac-sodium 20 g/ha at 20 DAT was effective for weed control and resulted in higher yield in farmers' fields in rice-rice cropping system as compared to pre-emergence herbicides alone.

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Direct seeded rice in north-western India: shift in weed flora and its management

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In recent years, direct seeded rice (DSR) has caught the attention of farmers as an alternate establishment method for rice in north-western India due to reduced labor costs, and savings in water and energy use (Yadav *et al.* 2011). However, absence of continuous flooding makes the field favourable for emergence of weeds and thus makes weed management more challenging in DSR.

METHODOLOGY

Field experiments on DSR were initiated in 2007-08 at CCS Haryana Agricultural University, Regional Research Station, Karnal. During initial three years, field experiments were conducted to study the changes in weed dynamics under DSR. Based on the understanding of weed dynamics, a series of field experiments on direct seeded *basmati* rice were conducted from 2008-09 to 2014-15 along with farmer participatory trials in different parts of Haryana.

RESULTS

Research undertaken at Research farm and at farmers' fields in Haryana showed that there was a quick shift in weed flora with change of establishment method from puddle transplanted rice (PTR) to DSR. Aerobic grass weeds such as *Leptochloa chinensis*, *Eragrostis spp.*, *Dactyloctenium aegyptium* and *Eleusine indica* which were minor weeds in PTR became major weeds in DSR. Infestation of sedges like *Cyperus rotundus* also increased under DSR. On the other hand, *Echinochloa crus-galli* still remains the dominant weed under puddle transplanted rice with little or no infestation of aerobic grass weed species. Weed infestation in DSR research trials was so high that in unweeded situations rice grain yield was reduced by more than 50%. In addition to the diverse weed flora, the prolonged weed emergence further added to the complexity of weed management in DSR. Within DSR, there was less and delayed weed emergence under *vattar* (moist) sowing of DSR than dry sowing (irrigating the field after sowing). Stale seedbed technique proved effective in reducing weed infestation in DSR, along with controlling previous season's volunteer rice plants. Inclusion of green cover crops like mungbean, cowpea and *Sesbania* also helped in decreasing the weed infestation in the main DSR crop, along with their added advantage as green/ brown manure manure.

Bispyribac-sodium 25 g/ha sprayed at 15-25 days after sowing (DAS) was quite effective against *Echinochloa crus-galli* and some broadleaf weed (BLW) species in DSR. Pre-emergence application of pendimethalin 1000 g/ha or pretilachlor + safener 500 g/ha or oxadiargyl 100 g/ha could be used to effectively control aerobic grass weeds such as *Dactyloctenium aegyptium*, *Leptochloa chinensis*, *Eragrostis spp.* and *Eleusine indica.* However, pendimethalin was the best among these herbicides, but soil moisture was crucial for its better efficacy (Yadav *et al.* 2011). Tank-mix of azimsulfuron 20 g/ha, pyrazosulfuron 25 g/ha, ethoxysulfuron 18.8 g/ha or metsulfuron + chlorimuron (ready-mix) 4 g/ha with bispyribac 25 g/ha also provided effective control of BLW and sedges along with *Echinochloa sp*; however, azimsulfuron and pyrazosulfuron were quite effective against sedges like *Cyperus rotundus*. Fenoxaprop (with safener) 60 g/ha was found promising post-emergence herbicide against aerobic grasses, but its tank-mix application was antagonistic on bispyribac. Cyhalofop-butyl could also be an early post-emergence herbicide against aerobic grass weeds. Farmers in north-western India have now widely adopted the use of pendimethalin 1000 g/ha followed by bispyribac 25 g/ha for broad-spectrum weed control in DSR. One hand-weeding may be given to prevent seed production by weeds that escape herbicide treatments. Development of effective weed management strategies for DSR has played an important role in the expansion of area beyond 0.1 million hectare under DSR in north-western India.

CONCLUSION

Aerobic grass weeds such as *Dactyloctenium aegyptium, Leptochloa chinensis, Eragrostis spp., Eleusine indica* etc and sedges like *Cyperus rotundus* which were minor weeds in PTR became major weeds in DSR. Pendimethalin 1000 g/ha (pre-emergence) followed by bispyribac sodium 25 g/ha (post-emergence) provided effective control of most of the weeds in DSR. In situations of high infestation of sedges like *Cyperus rotundus*, tank-mix of pyrazosulfuron 25 g/ha, azimsulfuron 20 g/ha or ethoxysulfuron 18.8 g/ha with bispyribac 25 g/ha may be done. Inclusion of green cover crops, and integration of stale seedbed and one hand-weeding may be desirable.

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Evaluation of new pre-mix mixture penoxsulam + cyhalofop-butyl for weed control in direct-seeded puddled rice

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Chemical weed control is easier and economical in direct seeded rice. But continuous usage of the same herbicides will lead to the problem of herbicide resistance in weeds. One of the ways to overcome herbicide resistance is the use of herbicide mixtures. Application of grass effective herbicide in combination with broad spectrum herbicide will provide better weed control (Mukherjee 2006). Hence a study was carried out to evaluate the efficacy of a combination of broad spectrum herbicide penoxsulam and grass effective herbicide cyhalofop-butyl.

METHODOLOGY

Field experiments were conducted at farmers' field in Kalliyoor panchayat situated at a latitude and longitude of 8.5º N and 76.9° E and 29 m above MSL during *Kharif* and *Rabi* 2014. The experiment was laid out in randomized block design replicated thrice with eight treatments *viz*., penoxsulam +cyhalofop-butyl 6% OD at four different doses, bispyribac-sodium 10 % SE at 25 g/ha, penoxsulam 24 SC at 22.5 g/ha, hand weeding twice at 20 and 40 DAS (days after sowing) and weedy check. The soil was clay loam, acidic in reaction, medium in N, P and K. The herbicides were applied 15 DAS with a spray volume of 500 l/ha. '*Kanchana*' (PTB 50) was used as the test variety with a seed rate of 100 kg/ha. The crop was fertilized with 70: 35: 35 kg N: P_2O_5: K_2O/ha. Data on weed growth and yield performance were recorded. The dehydrogenase activity of the soil was also assayed.

RESULTS

The weed flora was dominated by sedges (53.2%), broad leaf weeds (BLW) (34.7%) and grasses (12.2%). Dominant weed species present were *Schoenoplectus juncoides* and *Cyperus iria* (among sedges), *Ludwigia perennis* (among broad-leaf weeds) and *Isachne miliacea* (among grasses). The lowest density of weeds was observed in penoxsulam + cyhalofop applied at 135 g/ha which was on par with 125 and 130 g/ha (Table 1). Data on weed dry weight indicated that penoxsulam + cyhalofop applied at 125, 130 and 135 g/ha were significantly superior to penoxsulam, bispyribac-sodium and hand weeding. Das (2008) reported that application of herbicide mixtures resulted in better weed control than their individual components. Penoxsulam + cyhalofop applied at 135 g/ha recorded the lowest weed dry matter which was on par with 125 and 130 g/ha with a WCE of 98.3%, 97.5% and 97.8% respectively. The highest yield was recorded with penoxsulam + cyhalofop applied at 135 g/ha, while weedy check recorded the lowest yield. The yield enhancement in penoxsulam + cyhalofop applied at 125, 130 and 135 g/ha compared to hand weeding was 3.9, 6.11 and 6.65% and compared to penoxsulam was 5.4, 7.66 and 8.19%, respectively. Bispyribac-sodium recorded significantly lesser yield than other weed control treatments. Compared to hand weeding, herbicide treatments recorded higher B:C ratio due to low cost of cultivation. The B:C ratio was higher in penoxsulam + cyhalofop-butyl applied at 135 and 130 g/ha. As compared to other treatments, significantly higher dehydrogenase activity was observed in all tested doses of penoxsulam + cyhalofop-butyl, implying that it has no negative impact on soil microbial biomass.

Table 1. Weed growth, yield, dehydrogenase activity and economics as influenced by weed control treatments (pooled data of *Kharif* and *Rabi* 2014)

Treatment	Total weed density at 60 DAS (no/m^2)	Total weed dry weight at 60 DAS (g/m^2)	WCE (%)	Dehydrogenase activity (µg TPF released g/soil/ day) in soil (15 DAHA)	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (x10^3 `/ha)	B:C ratio
Penoxsulam + cyhalofop-butyl 120 g/ha	22.35(499.0)	4.32(18.1)	96.6	196.6	7.86	7.37	47.98	3.10
Penoxsulam + cyhalofop- butyl 125 g/ha	17.86(318.4)	3.76(13.6)	97.4	233.7	8.25	7.05	48.10	3.23
Penoxsulam + cyhalofop-butyl 130 g/ha	17.14(293.2)	3.54(12.0)	97.7	234.2	8.42	7.11	48.23	3.29
Penoxsulam + cyhalofop-butyl 135 g/ha	11.72(136.8)	3.09(9.0)	98.3	260.1	8.46	7.19	48.35	3.30
Bispyribac-sodium 25 g/ha	36.64(1341.9)	7.01(48.6)	90.8	176.3	7.45	7.25	46.91	3.01
Penoxsulam 22.5 g/ha	24.31(590.4)	4.95(24.0)	95.5	210.2	7.82	7.14	47.16	3.14
Hand weeding twice	27.01(729.0)	5.75(32.5)	93.9	160.3	7.93	6.87	50.48	2.97
Weedy check	57.23 (3274.7)	23.13(534.5)	-	164.9	4.26	6.76	44.48	1.88
CD (P=0.05)	2.55	0.82		18.9	0.26	NS		

Values in parentheses are original values; WCE-weed control efficiency; DAHA-days after herbicide application

CONCLUSION

It can be concluded that for better productivity and weed control in direct seeded puddled rice, post-emergence application of penoxsulam + cyhalofop-butyl at 130 or 135 g/ ha can be recommended**.**

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Weed competitive ability of direct-seeded rice genotypes

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In response to the increasing production costs and shortages of labour and water, farmers in drought prone areas are shifting from traditional transplanted rice to mechanized-sown dry-seeded rice (DSR). However, weeds are the major problem in DSR (Chauhan 2012) causing yield loss to an extent of 30 to 90%. Weeds are complex and diverse in DSR fields, and no single approach of weed management can control all weeds effectively. Rice genotypes vary in their growth and weed suppressing ability. The present investigation was undertaken to evaluate the performance of rice genotypes under different weed management practices.

METHODOLOGY

Seven rice genotypes viz. 'Sahbhagi Dhan', 'Sushk Samrat', 'IR83387-B-B-40-1', 'IR83387-B-B-27-4', 'IR83376-B-B-24-2', 'IR82870-11' and 'Abhishek' were evaluated under partial weedy (pendimethalin 1.0 kg/ha only) and weed free (pendimethalin 1.0 kg/ha fb bispyribac-sodium 30 g/ha at 20 days after sowing and two hand weeding at 45 and 65 days after sowing) conditions. The experiment was laid out in a split plot design in three replications. Pendimethalin 1.0 kg/ha (pre-emergence) was sprayed next day after sowing with knapsack sprayer fitted with flat fan nozzle using 500 l/ha spray volume. Bispyribac-sodium 30 g/ha as post-emergence was used at 4-6 leaf stage (20 days after sowing). Crop was raised under rainfed conditions with one protective irrigation.

RESULTS

Significantly higher grain yield (2.28 t/ha) was obtained in weed free plots (herbicide + hand weeding twice) as compared to partially weedy plots (treated with pendimethalin alone) (1.48 t/ha) (Table 1). Rice genotype 'IR83387-B-B-27-4' (2.99 t/ha) followed by 'Shusk Samrat' (2.86 t/ha) yielded maximum under weed free plots, while 'Abhishek' (1.83 t/ha) followed by 'IR83387-B-B-27-4' (1.75 t/ha) yielded maximum under partially weedy situation. Yield reduction due to weeds was higher in 'Shusk Samrat' (52.3%), while it was minimum in case of 'Abhishek' (11.1%). Weed management practices also significantly influenced the density and dry weight of weeds (Table 1). Under partial weedy condition, the weed density was minimum in plots with variety 'IR83387-B-B-40-1' (161) followed by 'IR83387-B-B-27-4' (176), while dry weight of weeds was lower in 'IR82870-11' (104 g/m^2) closely followed by 'Sushk Samrat' (112 g/m^2).

Table 1. Weed population, weed dry weight and grain yield of rice genotypes under different weed management practices

Rice genotypes (G)	Weed count (no/m^2)			Weed dry weight (g/m^2)			Grain yield (t/ha)			% yield reduction*
	W1	W2	mean	W1	W2	Mean	W1	W2	Mean	
'Sahbhagi Dhan'	81	189	135	92	135	114	2.41	1.23	1.82	48.8
'Shusk Samrat'	136	179	155	88	112	100	2.86	1.36	2.11	52.3
'IR83387-B-B-40-1'	109	161	135	72	123	97	1.98	1.48	1.73	25.4
'IR83387-B-B-27-4'	105	176	141	74	132	103	2.99	1.75	2.37	41.3
'IR83376-B-B-24-2'	96	186	141	119	125	122	2.26	1.27	1.77	43.5
'IR82870-11'	147	187	167	82	104	93	1.42	1.43	1.43	0
'Abhishek'	124	223	174	72	167	120	2.06	1.83	1.94	11.1
Mean	117	182	-	86	128	-	2.28	1.48	-	-
LSD (P=0.05)	W=38.6 G=27.7 WxG=39.2			W=18.6 G=24.1 WxG=34.1			W=0.35 G=0.37 WxG=0.52			

W1= Pendimethalin *fb* bispyribac-sodium + 2 HW; W2= Pendimethalin alone; * - Percent yield reduction over W1

CONCLUSION

Rice variety 'Abhishek' followed by 'IR83387-B-B-27-4' proved to be more weed competitive and produced maximum grain yield under partial weedy (pendimethalin alone) condition.

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Efficacy of Rinskor™ active against weed flora in different rice cultures of India

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Rice is the staple food for millions of people in India. It will be very challenging to feed the projected population of 1.7 billion people in India by 2050. Weeds in rice are one of the most important biological hindrances to yield increase. Weed infestations during the crop growing season can reduce rice yields 57-61% in transplanted rice and 64-66% in wet seeded rice as compared to season- long weed free situations (Mukherjee *et al.* 2008). Controlling weeds using herbicides is the most popular approach among rice farmers. Considering the current herbicides of choice are either ALS or ACCase mode of action, there is a need for effective herbicides with an alternative mode-of-action. Rinskor™ active is a new arylpicolinate herbicide that has as a synthetic auxin mode of action from Dow AgroSciences that specifically addresses this need. Field studies were conducted to evaluate the bioefficacy of Rinskor for weed control in two different rice cultures in India (transplanted and puddled direct-seeded rice).

METHODOLOGY

Field experiments were conducted to evaluate the efficacy of Rinskor (formulated as a NeoEC™ formulation) on weeds in transplanted (18 experiments) and puddled direct-seeded rice (16 experiments) during 3 crop seasons (*Kharif* 2013, *Rabi* 2013 and 2014, and *Kharif* 2014) across various sites in Haryana, Punjab, West Bengal, Andhra Pradesh, Telangana, and Chhattisgarh. Varying doses of Rinskor were compared with Vivaya™ (penoxsulam + cyhalofop 60 OD) and bispyribac-sodium (10% SC). All treatments were applied at the 4-8 leaf stage of weeds and were arranged in a randomized block design with three replications. A knap-sack sprayer fitted with a flood jet nozzle was used to apply the herbicide solutions. Weed density (number/m^2) by species was observed at 25 to 30 days after application. Weed count was subjected to percent Abbot transformation to calculate percent control from weed count in untreated plot.

RESULTS

The major weeds in field research site in transplanted rice were grasses, (*E. crus-galli), sedges (C. difformis* and *Scirpus spp.),* and broadleaf weeds *(Ammania* spp., *Ludwigia* spp., *Marsilea* spp., *Monochoria vaginalis* and *Sphenoclea zeylanica).* In puddled direct-seeded rice, the major weeds were grasses, (*E. crusgalli, E. colona), sedges (C. difformis)* and BLWs *(Ludwigia* spp. and *Monochoria vaginalis).*Similar to Vivaya and bispyribac applied at the recommended rates, Rinskor™ active at 25 g/ha provided 94% control of *E. crusgalli* in transplanted rice (Table 1). For sedges and broadleaf weeds, Rinskor™ at 25 g/ha provided control superior to bispyribac and comparable to Vivaya.

In puddled direct-seeded rice, Rinskor at 31.25 g/ha provided 85% control of *E. crusgalli* that was comparable to the control provided by Vivaya (84% control) and bispyribac (82% control) when applied at recommended rates. For the grass weed *E. colona* and the sedge weed *C. difformis*, Rinskor at 31.25 g/ha provided control significantly greater than the control provided by Vivaya and bispyribac at the recommended rates (Table 2). For the broadleaf weeds *Ludwigia* spp. and *Monochoria vaginalis*, Rinskor at 25 g/ha exhibited control (85-100%) that was comparable with Vivaya and bispyribac when applied at the recommended field rates.

CONCLUSION

Rinskor™ active is a new herbicide from Dow AgroSciences suitable for various kinds of rice cultures in India. As a novel herbicide with an auxinic mode of action, Rinskor will provide an alternative to current ALS and ACCase herbicide solutions. With excellent herbicidal efficacy when applied at 25 to 31.25 g/ha, Rinskor will provide rice growers a novel choice for superior control of key weeds in rice.

Table 1. Percent control of major weeds in transplanted rice

Treatment	Rinskor			Vivaya	Bispyribac-na
	(g/ha)				
Weed species	25	31.25	37.5	135	25
Grasses	Weed control (%)				
E. crusgalli	94	98	100	97	95
Sedges					
C. difformis	84	94	96	94	73
Scirpus spp.	81	93	98	92	71
Broad leaf weeds					
Ammania spp.	67	75	77	73	69
Ludwigia spp.	87	93	96	93	60
Marsilea spp.	100	100	100	100	87
Monochoria vaginalis	89	923	99	79	82
Sphenoclea zeylanica	86	87	83	94	70

Table 2. Percent control in puddled direct seeded rice

Treatment	Rinskor			Vivaya	Bispyribac na
	Dose (g/ha)				
Weed species	25	31.25	37.5	135	25
Grasses	Weed control (%)				
E. crusgalli	78	85	NA	84	82
E. colona	81	87	97	74	75
Sedges					
C. difformis	93	86	86	76	59
Broad leaf weed					
Ludwigia spp.	85	89	99	76	83
Monochoria vaginalis	100	100	100	100	100

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Use of dose-response relationship to identify herbicide's efficacy in a mixture

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Use of herbicides is established as a major method of weed control in agriculture. Studies on dose-response relationship is very important in weed research which is used to know the herbicide efficacy and mode of action. In order to optimise weed control efficacy and minimise the application costs, the use of herbicide mixtures has become very popular in many countries. This strategy also represents an important tool to avoid problems related to herbicide resistance, but it requires some preliminary information to assist farmers with the process of herbicide and dose selection. Keeping this in view, a field experiment was conducted to see the herbicides efficacy in mixture using dose response curve in rice crop.

METHODOLOGY

The field experiment was conducted in direct seeded rice during *Kharif* 2014 at experimental farm of ICAR-Directorate of Weed Research, Jabalpur. The soil of the experimental field was clay loam, of pH 6.9 and OC 0.71%, low in nitrogen, medium in available phosphorus and potassium. The experiment comprised of tank mixed treatment combinations of two herbicides viz. fenoxaprop and metsulfuron at different doses 30, 40, 50, 60 g/ha and 2.5, 3.0, 3.5, 4.0 g/ha respectively to control grassy and broad leaved weeds. The experiment was laid out in 5^2 factorial Randomized Block design with 3 replications. The field was mainly infested with *Echinochloa colona, Alternanthera sessilis, Eclipta alba, Ludwigia adscendenus, Dinebra retroflexa, Cyperus iria, Ammania baccifera and Commelina benghalensis.* Twelve days after the application of herbicides, data on percent (%) weed control by different doses of the two herbicides was observed and dose response models were fitted to the data. Among many models, dose response Hill model was found to be best fit for the data. Dose-Response Hill function is given by:

$$y = \delta + \frac{\alpha x^{\theta}}{\varphi^{\theta} + x^{\theta}}$$

Where, y is the % weed control, δ is intercept, $\alpha = y_{max}$, x denote the dose, θ is the hill coefficient of sigmoidicity and φ denote the ED_{50} value or the dose for which 50% control is obtained. Before fitting the model, error assumptions (normality, randomness and homogeneity of the error variance) were confirmed with studentized residuals and Shapiro-Wilk normality test (Onofri *et al.* 2010). Data was found to be non-normal, therefore arc sine transformation was applied to the data to make it normal. Hill model describes the relationship between the dose of the herbicides and %weed control for the present data.

RESULTS

Perusal of the data revealed that fenoxaprop controls all grassy weeds at recommended dose even at lower dose. On the other hand, metsulfuron controls all broad leaved weeds at recommended dose but fails to control weeds at lower dose. From the investigation of fenoxaprop in different doses viz. 30, 40, 50 and 60g/ha, a hill model was fitted to fenoxaprop alone as well as in mixture data. Analysis revealed that almost 100% control of grassy weeds was observed with full dose of fenoxaprop when applied alone. But when applied in mixture its efficacy decreased to 96%. Its ED_{50} value was estimated as 39.8 g/ha from the fitted model when used alone but it was increased to 45.7 g/ha when used in mixture. Further, it is clear from the analysis that when fenoxaprop was applied in mixture with metsulfuron, its efficacy decreased due to antagonistic effect of metsulfuron. Same trend was observed with metsulfuron data after fitting the dose-response hill model. It can be inferred from the data that when metsulfuron was applied alone, it controlled almost 95% of broad leaved weeds and ED_{50} value was obtained as 3.43 g/ha. But, when it was applied in mixture with fenoxaprop, its efficacy reduced to 90% with ED_{50} value as 3.62 g/ha. It reveals the presence of antagonistic effect of fenoxaprop on metsulfuron when used in mixture.

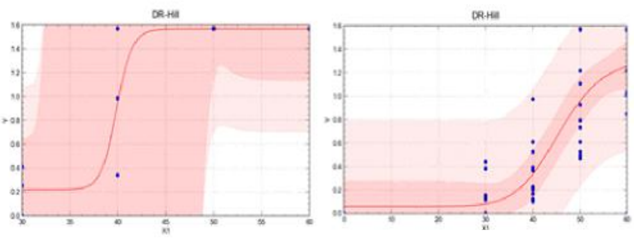

Fig. 1. Dose response curve of %weed control (y) of grassy weeds using fenoxaprop alone (a) and in mixture (b).

Fitted hill equation: y=0.221+ (1.54*dose^49.4)/(39.8^49.4+ dose^49.4), y=0.062+(1.28*dose^9.58)/(45.7^9.58+ dose^9.58) respectively.

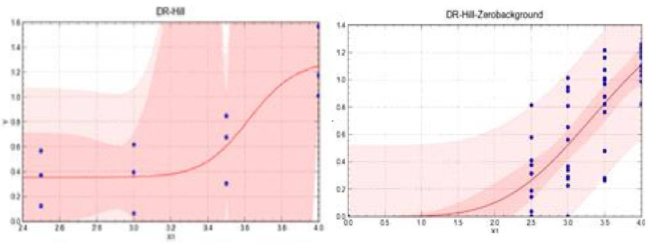

Fig. 2. Dose response curve of %weed control (y) of broad leaved weeds using metsulfuron alone (c) and in mixture (d).

Fitted hill equation: y=0.355+(1.25*dose^33.02)/(3.43^33.02 + dose^33.02), y=(1.12*dose^4.7)/(3.62^4.7+ dose^4.7) respectively.

CONCLUSION

Fenoxaprop and metsulfuron expressed the antagonistic effect on each other when used in mixture which ultimately decreased their efficacy.

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Technical Session 2

Weed biology and ecology

Management of weedy rice – Indian experience

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In India, the shift in the rice crop establishment method from transplanting to direct sowing of pre-germinated seeds, dependence on pesticides especially herbicides, reduced tillage practices, acute shortage and high cost of labor *etc.* have led to several biotic and abiotic stresses in rice cultivation (Wang and Chang, 2009). A perennial constraint in rice cultivation is weed infestation and of late weedy rice infestation has become a serious threat in the rice belts of India. Morphological similarity of weedy rice to cultivated rice, variable seed dormancy, early seed shattering nature, staggered germination and high competitiveness of weedy rice make hand weeding/rouging incomplete and ineffective (Chauhan 2013). Lack of biochemical differences make selective herbicidal control of weedy rice in cropped field difficult. Surveys conducted in India, have indicated the severe incidence of weedy rice in the traditional rice belts of South and North East India compared to the new rice belts of Punjab and Haryana. Wild and weedy forms are problematic in Eastern U.P., Bihar, Orissa, Manipur, Assam and West Bengal and in southern states of Andhra Pradesh, Karnataka, Tamil Nadu and Kerala. During the recent years, heavy infestation of weedy rice resulting in huge reduction in yield (50-70%) has forced the farmers to abandon the crop even without harvesting and leave the land fallow in the subsequent years. Therefore, detailed studies were taken on the infestation, biology and control of weedy rice.

METHODOLOGY

Stratified survey was done in all panchayaths (covering representative polders in a panchayath) in the major rice belts of Kerala (Kuttanad, Palakkad and Kole) during 2011-13, to study the extent of incidence of weedy rice in different agro-ecological conditions of Kerala. The role of hull induced seed dormancy was studied by Scanning Electron Microscope and by testing the germination of intact seeds as well as seeds with scraped hull (both fully matured and half matured grains). Management of weedy rice was attempted in three ways, *viz*. stale seed bed technique, modified application of pre-emergence herbicides and direct contact application of herbicides for post- emergence control of weedy rice. Reduction in the incidence of weedy rice or drying of weedy rice plants was recorded to assess the efficiency of the treatments.

RESULTS

More than 65% of the major rice belts of Kerala had low to severe (1-13 weedy rice plants /m^2) weedy rice infestation. Seeds shatter within 15 days after flowering and by the time of harvest of the crop most of the seeds had shed and enriched the soil seed bank. Electron microscope studies have shown that weedy rice seeds possess hull induced dormancy due to tight packing and increased overlapping of lemma and palea, making the seeds impermeable to water. The mature dried seeds do not germinate immediately after shattering and majority of them took 45- 60 days, while the seeds at physiological maturity germinated rapidly within 6-12 days and some seeds remained viable for long periods under deep burial and submergence.

Stale seed bed technique proved effective for depletion of soil seed bank. There was 91% decrease in the weedy rice population in double staling. It was observed that destruction of the first flush of weeds germinated from the soil seed bank by wet tillage followed by second staling with herbicide application decreased the weedy rice population by more than 70% in the succeeding crop compared to dry tillage. There was 25% increase in yield in double stale with wet tillage in between stales over dry tillage.

Oxyfluorfen 2-3 kg/ha applied to a thin film of standing water three days before sowing gave 50-60% control of weedy rice. After herbicide application, the water was allowed to evaporate/infiltrate leaving the field free of standing water and then pre-germinated rice seeds were broadcasted. The yield increase obtained was 20-25% over the control by this management strategy. In addition to weedy rice, other weeds were also got controlled by pre- sowing surface application of oxyfluorfen.

Utilizing the earliness in flowering of weedy rice plants compared to rice plants (10-15 days) and consequent difference in height of weedy rice panicles and rice plant at 60-65 DAS, it is possible to dry 75-85% ear heads of weedy rice by direct contact application of broad-spectrum non selective herbicides at 10-15% concentration of the formulated product using wick applicator. In Kerala Agricultural University, a wiper applicator has been developed and found effective on field testing. Use of paraquat and glufosinate-ammonium could dry only the ear heads of weedy rice whereas glyphosate could dry the plant also.

CONCLUSION

Effective and economical management of weedy rice is possible by the integrated use of different options for management, *viz*. stale seed bed technique, modified application of pre emergence herbicides and direct contact application of herbicides for post-emergence control of weedy rice depending on the intensity of infestation. The promising technologies standardized for managing weedy rice were demonstrated in the farmers' field in a participatory mode, with appropriate modifications to suit the local conditions. In areas of severe infestation, integration of more than one method is recommended.

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Weed density and nitrogen effects on the interference of *Phalaris minor* in wheat

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Growing high-yielding dwarf varieties of wheat has led to a shift in weed flora from broad-leaved weed dominance in 1960s to grass weed menace in early 1970s and *Phalaris minor* dominance in late 1970s. Also *P. minor* has developed resistance to isoproturon (Malik and Singh, 1993) and cross-resistance biotypes to clodinafop-propargyl (Das *et al.* 2014). Among weeds, *P. minor* Retz. is single most dominant grassy weed in northern Indian plains causing significant yield losses (Chhokar *et al.* 2012). Having similar morphology / plant-architecture with wheat, *P. minor* is likely to cause severe interference with wheat. The growth factors, particularly, N may intensify the interference effect but less studied in the context of climate change. The effect of *P. minor* densities on wheat in response to N application may alter the crop-weed balance but hardly documented. Therefore, this experiment was undertaken.

METHODOLOGY

The field experiment was conducted at Indian Agricultural Research Institute, New Delhi, India, during winter of 2014. The site was located at latitude of 28°40' N and longitude of 77°12' E, and an altitude of 228.6 meters above the mean sea level. The climate of Delhi is sub-tropical and semi-arid type with hot and dry summer and cold winters and falls under the agro-climatic zone 'Trans-Gangetic plains'. The experiment was laid out in a split plot design with 3 replications consisting of 21 treatment combinations: 3 N doses (100 kg N/ha, 150 kg N/ha and 180 kg N/ha) in main plot and 4 *Phalaris minor* densities (10, 20, 40 and 80 plants/ m^2) and 3 controls (unweeded control without *Phalaris*, unweeded control mixed population and weed free check) in sub plots. The wheat variety 'HD 2967' was sown with seed-cum fertilizer drill by using 100 kg seed/ha at row spacing of 22.5 cm. The seed of *Phalaris minor* was broadcasted at the time of sowing to maintain the desired densities. The herbicide metsulfuron at 5 g/ha was used at 20 DAS of wheat in *Phalaris* plots to remove the broad-leaved weeds. All recommended package of practices were used to grow wheat crop including recommended dose of P and K (60 kg P_2O_5 and 40 kg K_2O/ha, respectively). The data on *Phalaris* tillers and dry weight of weeds, and yield and yield attributes of wheat were recorded and analyzed statistically by using SAS version 9.3 in the computer.

RESULTS

Yield attributes and grain yield were significantly improved as the doses of N increased from 100-180 kg/ha (Table 1). Significantly higher grain yield of wheat (5.41 t/ha) was observed with the application of 180 kg N/ha followed by 150 kg (4.77 t/ha) and 100 kg N/ha (3.57 t/ha). Similarly *P. minor* densities also influenced yield and yield attributing characters of wheat. Increase in the density of *P. minor* from 10 plants/m^2 to 80 plants/m^2, the yield of wheat was reduced from 5.06-3.82 t/ha. The yield reduction was 9.16-31.42% respectively over weed-free check. Hussain *et al.* (2014) in Pakistan reported that decrease in yield of wheat was almost proportional to increase in densities of *P. minor* from 10-40 plants/m^2. Tillers and dry weight of *P. minor* were also influenced by N doses and *P. minor* density (Table 1). Higher number of tillers and dry weight of *P. minor* were observed under lower doses of nitrogen during 60 DAS over higher dose of 150 and 180 kg N/ha. It was due to the higher growth of wheat, causing smothering effect. In case of *P. minor* densities significantly higher tillers and dry weight were observed under *Phalaris* density of 80 plants/m^2at 60 DAS.

Table 1.Yield and yield attributes of wheat and dry weight and tillers of *Phalaris minor* as influenced by N doses and densities

Treatment	Effective tillers (no./m row length)	No. of grains/spike	Grain yield (t/ha)	*Phalaris minor* tillers (no./m^2) 60 DAS	Dry weight of weeds (g/m^2) 60 DAS
Nitrogen dose					
100 kg N /ha	78.48	40.27	3.57	7.89*	168.29
150 kg N/ha	98.86	47.98	4.77	6.60	123.19
180 kg N/ha	108.95	51.11	5.41	5.43	76.14
LSD (*P*=0.05)	4.33	1.31	0.54	1.357	19.32
Phalaris minor density					
10 plants/m^2	107.89	50.59	5.06	7.02	59.89
20 plants/m^2	102.78	48.97	4.78	8.24	94.11
40 plants/m^2	89.33	45.53	4.39	10.03	147.89
80 plants/m^2	84.67	43.31	3.82	13.05	296.11
Unweeded control without *Phalaris*	87.56	44.00	4.41	1.00	79.78
Unweeded control mixed population	81.44	41.28	4.07	6.13	180.00
Weed free check	114.33	51.50	5.57	1.00	0.00
LSD (P=0.05)	3.39	1.57	0.26	0.77	11.39

*Data transformed to square root transformation

CONCLUSION

Results show that the doses of N and *Phalaris minor* densities significantly influence the competition between *Phalaris* and wheat crop. Higher dose of 180 and 150 kg N/ha proved beneficial towards reduction of *P. minor* interference. However, higher density of *P. minor* reduce the effect of N. The effect of higher dose of N was more prominent at the lower density of 10-20 *Phalaris* plants/m^2.

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Weed survey in sweet corn (*Zea mays L. saccharata)* in Sumedang and Bandung

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The presence of weeds in sweet corn crop can reduce corn yield and seed quality.The competition level between crop and weed depends on four factors: stage of crop growth, weed density, water stress and nutrient levels and associated weeds pecies. The objective of this study was to investigate the dominant weed species on sweet corn in two sweet corn production centers in West Java (Sumedang and Bandung districts).

METHODOLOGY

The research was carried out in Sumedang and Bandung district, each district consisted of 12 sweet corn farms. The experiment was carried out from March 2014 until July 2014. The experimental design used was descriptive method with survey method. There were 12 observations on each area, so there were 24 observations. The research in Sumedang was done in villages: Mekarbakti, Raharja, Sukawangi, Ciptasari, Sukasari, Mekarsari and Sindangsari, whereas in Bandung there searched villages were: Arjasari, Pinggirsari, Ancol Mekar, Cinunuk and Cibiru Wetan.

RESULTS

The dominant weeds in Sumedang and Bandung were *Ageratum conyzoides* L. and *Cyperus rotundus* L.. Comparison of Coefficient Value Communities (C) between district Sumedang and Bandung was of 69.75% indicating the lack of similarity among weed population of both areas. The total value of Species Diversity Index (H') in Sub district Pamulihan was 1.18; Subdistrict Sukasari was 1.12; Sub district Arjasari was 1.39; and Sub district Cileunyi was 1.35 which indicates a relatively low diversity category. The total value of species Similarity Index (E) in the Sub district Pamulihan was 0.79; Sub district Sukasari was 0.66; Sub district Arjasari was 0.79; and Sub district Cileunyi was 0.80 showing that the similarity was high.

CONCLUSION

The dominant weeds in Sumedang and Bandung were *Ageratum conyzoides* L. and *Cyperus rotundus* L. Differences in species diversity index were observed among various provinces.

Weed flora of aerobic rice in the coastal region of Karaikal, Puducherry

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Aerobic rice system has been evolved as the most promising water saving technology in rice culture wherein the rice is established by direct seeding in non-puddled and non-flooded fields (Anwar *et al*. 2010). In addition, aerobic rice requires less labour and capital input with saving of 29% of the total rice production cost. In aerobic rice system, the dry tillage and aerobic soil conditions are highly conducive for germination and higher growth of weeds which results in greater rice grain yield losses as compared to puddle transplanted rice. Uncontrolled weeds reduce the yield by 96-100% in dry direct-seeded rice (Maity and Mukherjee, 2008). Hence, developing an effective weed management approach has been a challenge for widespread adoption of aerobic rice cultivation. It is essential to know the species composition of weed flora and their life forms in order to identify a suitable method for managing weeds. Hence, this study was undertaken to analyze the weed flora associated with aerobic rice in the coastal region of Karaikal, U.T. of Puducherry.

METHODOLOGY

A field experiment was conducted during *Rabi* 2013 in the farm lands of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry. The soil of the experimental site was loamy sand in texture and pH was alkaline (8.2). The fertility status of the soil was low in available nitrogen (0.60 t/ha) and phosphorus (0.10 t/ha) and medium in available potassium (1.84 t/ha). A medium duration (135 days) rice cv. 'ADT(R) 46' was sown on September 5, 2013 and the recommended package of practices for aerobic rice was followed. The data on weed flora, absolute density and relative density were recorded at 30 and 60 days after seeding (DAS), using a list quadrat by following the standard procedures.

RESULTS

A diverse weed flora was observed in aerobic rice field at Karaikal region. Totally, 29 species (Table 1) of weeds belonging to 22 genera and 17 families were noticed in the experimental field of aerobic rice. Four of them were grasses, six were sedges and nineteen were broad leaved. Out of these 29 species, five were perennials and the rest were annuals.

During initial stages of rice growth, sedges dominated (38.3%) the experimental field while at later stages (60 DAS) broad leaved weeds dominated (42.5%). Grasses were relatively less dominant at both 30 and 60 DAS. *Cyperus haspan* L., and *Scirpus articulatus* among the sedges and *Corchorus tridens* L., *Marsilea quadrifolia* L., *Melochia corcorifolia* L., *Sphaeranthus indicus* L. and *Trianthema portulacastrum* L. among the broad leaved weeds were observed at later stages of crop growth (90 DAS and later).

CONCLUSION

In aerobic rice fields of Karaikal, U.T. of Puducherry, and the most predominant weeds were: *Echinochloa colona* Link. *fb Echinochloa cruss-galli* (L.) Beauv. (among the grasses); *Cyperus difformis* L. *fb Cyperus iria* L. (among sedges) and *Ludwigia abyssinica* (among the broad leaved weeds).

Table 1. Weeds density and relative density in aerobic rice, Karaikal

S.no	Name	Family	Life Form	Weed density (No./m^2)		Relative density (%)	
				30 DAS	60 DAS	30 DAS	60 DAS
1.	*Echinochloa colona*. Link.	Poaceae	Annual	265.0	362.3	17.9	28.1
2.	*Echinochloa cruss-galli* L.	Poaceae	Annual	163.0	79.0	11.0	6.1
3.	*Leptochloa chinensis* (L.) Nees.	Poaceae	Annual	0.0	16.0	0.0	1.2
4.	*Panicum repens* L.	Poaceae	Perennial	0.0	4.0	0.0	0.3
	Total grasses			428.0	461.3	28.9	35.7
1.	*Cyperus difformis* L.	Cyperaceae	Annual	293.0	125.0	19.8	9.7
2.	*Cyperus haspan* L.	Cyperaceae	Perennial	--	--	--	--
3.	*Cyperus iria* L.	Cyperaceae	Annual	146.7	108.0	9.9	8.4
4.	*Cyperus rotundus* L.	Cyperaceae	Perennial	127.0	32.3	8.6	2.5
5.	*Fimbristylis miliacea* L.	Cyperaceae	Annual	0.0	16.0	0.0	1.2
6.	*Scirpus articulates*	Cyperaceae	Annual	--	--	--	--
	Total sedges			566.7	281.3	38.3	21.8
1.	*Aeschynomene indica* L.	Fabaceae	Annual	0.0	24.0	0.0	1.9
2.	*Aponogeton monostachyon* L.	Aponogetonaceae	Annual	4.0	12.0	0.3	0.9
3.	*Bergia capensis* L.	Elatinaceae	Annual	0.0	11.0	0.0	0.8
4.	*Cleome viscosa* L.	Capparidaceae	Annual	0.0	17.0	0.0	1.3
5.	*Corchorus tridens* L.	Tiliaceae	Annual	--	--	--	--
6.	*Eclipta alba* (L.) Hassk.	Asteraceae	Annual	8.0	5.0	0.5	0.4
7.	*Glinus oppositifolius* L.	Molluginaceae	Annual	0.0	6.0	0.0	0.5
8.	*Hydrolea zeylanica* (L.) Vahl.	Hydrophyllaceae	Perennial	0.0	33.0	0.0	2.6
9.	*Lindernia crustacea*	Scrophulariaceae	Annual	0.0	19.0	0.0	1.5
10.	*Lindernia oppositifolia*	Scrophulariaceae	Annual	8.0	38.0	0.5	2.9
11.	*Lindernia procumbens* (Krock.)	Scrophulariaceae	Annual	0.0	18.0	0.0	1.4
12.	*Ludwigia abyssinica*	Onagraceae	Annual	326.4	361.0	22.0	28.0
13.	*Ludwigia parviflora* Roxb.	Onagraceae	Annual	132.3	0.0	8.9	0.0
14.	*Marsilea quadrifolia* L.	Marsileceae	Perennial	--	--	--	--
15.	*Melochia corcorifolia* L.	Sterculiaceae	Annual	--	--	--	--
16.	*Oldenlandia corymbosa* L.	Rubiaceae	Annual	8.0	0.0	0.6	0.0
17.	*Phyllanthus niruri* L.	Euphorbiaceae	Annual	0.0	4.0	0.0	0.3
18.	*Sphaeranthus indicus* L.	Asteraceae	Annual	--	--	--	--
19.	*Trianthema portulacastrum* L.	Aizoaceae	Annual	--	--	--	--
	Total broad leaved weeds			486.7	548.0	32.9	42.5
	All weeds			1481.4	1290.6	100.0	100.0

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Technical Session 3

Weed biology and ecology including impact of changing climate

Effect of resource conservation module of rice on weed infestation and sheath blight disease

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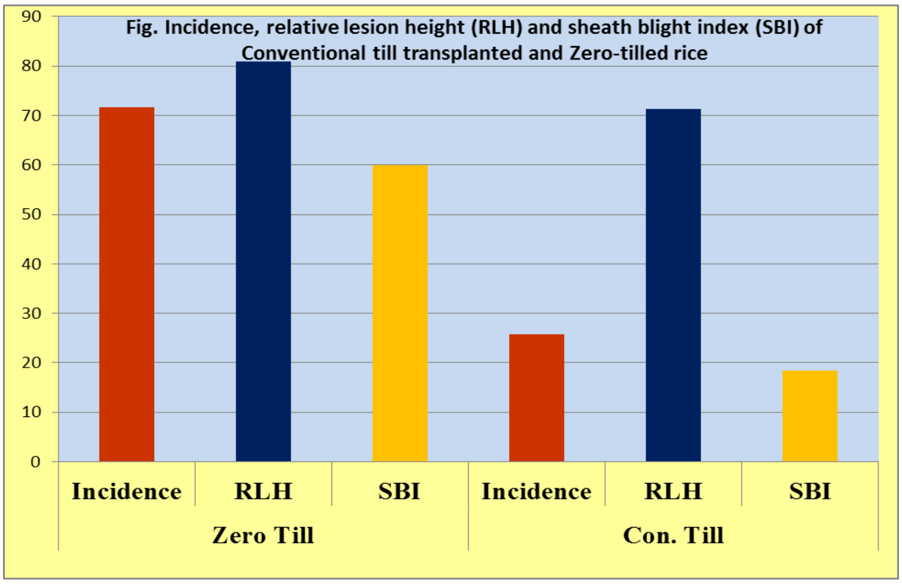
Resource conservation in agriculture is the prime concern under changing climatic scenarios. Direct seeded zero-tilled rice is the growing area under resource saving techniques in many parts of the world. The success of direct seeded zero-tilled rice largely depends upon the sound weed management practices (Mishra and Singh, 2012). The present study aimed to compare the direct seeded zero-tilled rice with conventionally tilled transplanted rice with respect to weed infestation and sheath blight attack.

METHODOLOGY

A study was conducted at the research farm of ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, India during 2013-14. The soil of the research farm was sandy loam. Two treatments *i.e.* direct seeded zero-till rice and conventionally tilled transplanted rice were evaluated in a randomized block design with 18 replications. The hybrid rice variety PRH 10 was taken into the study. Direct seeding of rice was performed through a Pantnagar zero-till–ferti-drill in the month of June. The nursery for transplanting was also laid on the same date as in case of direct seeding and transplanting of 25 days old seedlings was done manually. Two hand weedings, first at 35 DAS/DAT and second at 70 DAS/DAT were performed in both the treatments. Rests of the recommended cultural practices were performed as and when required. Observations on weed infestation, weed biomass, and sheath blight severity were taken at 90 DAS/DAT after panicle emergence.

RESULTS

Maximum weed biomass (126.3 g/m^2) was recorded in zero-till rice as compared to conventionally tilled transplanted rice (8.6 g/m^2). Perennial weed species like *Cynodon dactylon* and *Eleusine indica* dominated in zero-tilled plots. However, the sheath blight disease of rice caused by the fungus *Rhizoctonia solani*, was deadly severe in zero-till rice when compared to conventionally tilled transplanted rice. The incidence, relative lesion height and sheath blight index (71.7, 80.8, and 60.0% respectively) were higher in zero-till rice when compared to transplanted rice (25.83, 71.20, and 18.4%, respectively). Higher infestation of perennial weed species like *Cynodon dactylon* aggravated the sheath blight index in zero-till rice by facilitating its horizontal spread within the crop. Other weed species like *Paspalum distichum*, *Sorghum halepense*, *Echinochloa glabrescens* and *Dactyloctenium aegyptium* were also found to harbor the sheath blight pathogen (*Rhizoctonia solani*) in the rice field.



CONCLUSION

There was higher weed infestation particularly of perennial type and sheath blight severity in direct seeded zero-till rice as compared to conventionally tilled transplanted rice. Hence, the long term sustainability of resource conservation modules like zero-till rice will depend upon sound integrated weed, pest, and disease management strategies.

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Field host range and host specificity of *Anomalococcus indicus* (Hemiptera: Lecanodiaspididae): a potential biological control agent for prickly acacia *Vachellia nilotica* sp. *Indica* in Australia

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Prickly acacia (*Vachellia nilotica* subsp. *indica*), a native of the Indian subcontinent, is a serious weed of the grazing areas of northern Australia and is a target for classical biological control. Plant genotype and climatic similarities has accelerated a five year biological control project based in India since September 2008. Three years systematic surveys on prickly acacias at its natural host range in India revealed 94 different species of insects belonging to five families (Dhileepan *et al*. 2013).The sap sucking scale insect *Anomalococcus indicus* is one of the most promising agents prioritized as a potential biological control agent for further studies based on its field host range, field abundance and damage levels (Dhileepan *et al*. 2013). *A. indicus* available throughout the year was found more abundant in summer and late spring (January – March and September- December) in Tamil Nadu, India and it was previously recorded on *V. nilotica*, *V. farnesiana*, *V. leucophloea*, *Senegaliachundra*, *Ziziphusmauritiana* (Baksha and Islam 1996). This paper describes the field host range and host specificity studies and also discusses the possibility of using this insect species as a potential biological control agent of prickly acacia.

METHODOLOGY

Field host rage

A systematic survey was carried out in 2008-2011 in the states in Tamil Nadu and Karnataka. The survey sites were predominantly forestry plantations in tank beds, and isolated plants on roadside and tank bunds of agricultural lands. The survey efforts were more systematic and rigorous; where different districts and areas were covered at different months on the basis of accessibility representing varied climatic regions and sampled at quarterly intervals. During the surveys, other acacia species nearby and reported species were also sampled to monitor the natural host range of prioritized agents recorded on *A. nilotica* sp. indica.

Host specificity studies

No-choice host specificity testing of *A. indicus* was carried out at the insectary of Institute of Forest Genetics and Tree Bradding, Coimbatore by exposing with gravid females infested stem cuttings. The test plants used in the study were *Vachellia nilotica* sp. *tomentosa* (Benth.) Kyal. & Boatwr., *Vachelliatortilis* (Forssk.) Galasso and Banfi, *Vachellia planifrons* Wright and Arn., *Vachellia leucophloea* (Roxb.) Maslin, Seigler and Ebinger, *Senegalia mellifera* (M. Vahl) Seigler and Ebinger, *Senegalia catechu* (L.f.) P.J.H.Hurter and Mabb., *Senegalia ferruginea* (DC.) Pedley, *Vachellia arriculiformis* A.Cunn. ex Benth., *Vachellia farnesiana* (L.) Willd., (R.T. Baker) (all Fabaceae) and *Piper nigrum* (Piperaceae). Each plant species was replicated twenty times and each test plant tied with 15 cm infested stem cutting with10 gravid females. Data on duration to spreading and number of adults, nymphs survived on the tests plants were statistically analyzed.

RESULTS

Field host range

All the survey sites had the incidence of *A. indicus* which was recorded commonly on *V. nilotica* subspecies, *V. nilotica* sp. *indica*, *V. nilotica* sp. *tomentosa*, *V. nilotica* sp. *subalata* and *V. nilotica* sp. *cupressiformis.* In few occasions, the scale insect was recorded on *V. tortilis* and asingle occasion on *A. leucophloea* in survey. During the field surveys in southern India, the scale insect was not on other previously reported hosts.

Host specificity studies

No- choice test

The hatching nymph from female egg sac is to be finding difficultly, but after 3 to 4 molt it's visible. There appeared to be no dispersal on the locally available Acacia species and there was no young once found on all of these species, *V. nilotica* sub *species* and *V. tortilis* until 60 days experiment began (Table.1). The nymphs spreading were noticed in 19 ± 2.64, 23 ± 3.11 and 31 ± 4.03 days on prickly acacia and *V. nilotica* sp. *tomentosa* and *V. tortilis* respectively. Ants moving were evident on stems of these species. However the intensity of the scale population significantly varied among the infested plant species (Fig. 1). High population and gradually increased trend was noticed on the control plant (680 ± 2.84), followed that the *V. nilotica* sp. *tomentosa* had second highest population (450 ± 3.64) after end of the study; rest of the species had known number of scales population. Severe infestation was noticed only on *V. nilotica* sub species and the seedlings totally dried with 90 days. The experiment also revealed that the percent of the nymphs developed to adults varied among the infected test plant species (Table. 1). About 64±3.45% nymphs were developed to adults on control plants, similarly 51 ± 3.27% nymphs can mature as adults on *V. nilotica* sp. *tomentosa*. The least percentage (12 ± 5.61) was noticed on test plant species *V. farnesiana*.

Table 1. Proportion of *A. indicus*, nymphsthat developed into adult on various non-target plants in no-choice host specificity tests

Test plants	Duration of spreading (days)	% Nymph developed to adult	% seedlings mortality
Acacia nilotica ssp. *indica (control)*	19 ± 2.64	64 ± 3.45	100 ± 0.0
Acacia nilotica sp. *tomentosa*	23 ± 3.11	51 ± 3.27	100 ± 0.0
Acacia tortilis	31 ± 4.03	16 ± 5.48	10 ± 2.59
Acacia farnesiana	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia ferruginea	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia auriculiformis	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia catechu	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia mellifera	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia planiferons	0 ± 0.0	0 ± 0.0	0 ± 0.0
Acacia leucophloea	0 ± 0.0	0 ± 0.0	0 ± 0.0
Piper nigrum	0 ± 0.0	0 ± 0.0	0 ± 0.0

Mean of twenty replicates (± standard error).

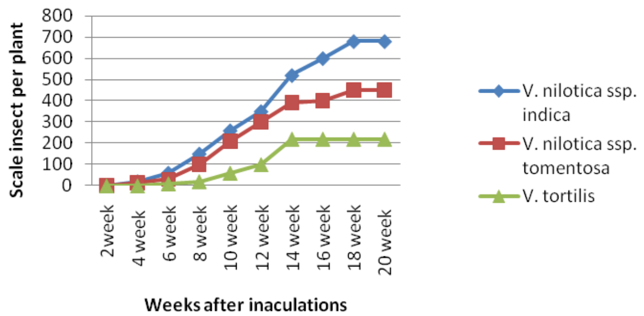

Fig 1. Proportion of *A. indicus* surviving on various test plants by no-choice host specificity tests over time

CONCLUSION

The scale insect *Anomalococcus indicus* is host specific on *V. nilotica* sub species in field. Preliminary tests thus reveals that the scale insects were abundant and causing severe damaging on all stages of *V. nilotica* sp. *indica* in Tamil Nadu, India. The scale has extensive generations and produced enormous population in a year and it might quickly reach damaging population level; if in Australia, free for natural enemies, hurriedly killed the prickly acacia than the native.

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Exotic weed seeds in the imported germplasm

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The import of seeds and planting material meant for research in various crop improvement programs is a potential and inadvertent source of introducing exotic weeds into new areas and this may cause severe damage to crop production. National Bureau of Plant Genetic Resources is the nodal agency to undertake the quarantine processing of germplasm including transgenic material introduced into the country for research purposes. Exotic weed seeds have been intercepted on many occasions from seed material (Singh *et al.* 2010). In view of the above, seeds and planting material imported through the Bureau was screened for weed seeds especially for the presence of exotic weed seeds.

METHODOLOGY

During 2010-12, a total of 183862 seed samples were imported from different countries. All samples were examined for weed seeds by passing through sieves of different pore sizes. Then each sample was spread in a thin uniform layer on a clean white drawing sheet and examined with the help of illuminated magnifier. All weed seeds were collected and then segregated into different types on the basis of their shape, size, colour, texture and presence of any attachment. Percentage incidence on number basis, viability and weed risk assessment score of different weed seeds were determined. Weed seeds were identified on the basis of their morphological characters and in few cases, weed seeds were subjected to grow out test in isolation and identified on the basis of vegetative and floral characters. All the weed seeds were devitalized using heat treatment at 120^0 C for 30 minutes.

RESULTS

A total of 32 weed species were intercepted in 166 samples. Among 32 weed species, 17 are exotic to India (Holm *et al.* 1997). Maximum exotic weeds were intercepted in the seeds imported from Switzerland followed by USA. Weed seeds were separated from contaminated samples by mechanical cleaning and weed free material was released to the importers. It is evident that all the weed seeds were found viable even after long storage. Weed risk assessment (WRA) score ranged from 07 to 18 and revealed that all the intercepted exotic weeds have potential to become problematic weeds in India. Particulars of weed seeds, their percentage incidence, viability and WRA score are given in Table 1.

Table 1. Exotic weeds intercepted, their percentage, viability and WRA score

Weed species	Crop	Country	Per cent incidence	Viability (%)	WRA score
Bifora testiculata	*Triticum aestivum*	Australia, Mexico	0.009	25	08
Bromus tectorum	*T.aestivum*	Switzerland	0.004	30	16
Cichorium spinosum	*Trifolium alexandrinum*	Egypt	0.023	58	16
Croton capitatus	*Oryza sativa*	USA	0.008	10	10
Echinochloa crus-pavonis	*O. sativa*	Argentina	0.002	72	18
Galium trifidum	*T. aestivum*	Germany	0.003	20	11
Jacquemontiat amnifolia	*O. sativa*	USA	0.001	12	10
Lamiumamplexicaule	*Medicago lupulina*	Switzerland	0.006	16	08
Lithospermum arvense	*Medicago* sp.	New Zealand	0.007	55	09
Polygonum argyrocoleon	*T.aestivum*	Mexico	0.012	60	12
Silenenoctiflora	*Brassica oleracea*	Netherlands	0.002	30	13
Sinapsis arvensis	*O. sativa*	USA	0.038	60	10
Trifolium bifidum	*Pennisetum purpureum*	Ethiopia	0.002	70	08
Trifolium pretense	*Trigonellafoenum graecum*	Syria	0.021	75	07
Vicia angustifolia	*M. lupulina*	Switzerland	0.015	70	12
Vicia tetrasperma	*M. lupulina*	Switzerland	0.001	80	11
Vicia villosa	*M. lupulina*	Switzerland	0.005	60	10

CONCLUSION

Observations indicate that import of seeds could be source of introduction and dissemination of dangerous and potentially dangerous exotic weed seeds. It is necessary to evolve suitable quarantine measures/regulations to prevent introduction of such exotic weeds into our country.

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Characterizing weed flora, shifts and nesting capacity of habitats in deep water rice areas of Assam

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Deep water rice (DWR) cultivation is not only a culture of rice production in low lying areas but also a system of trapping carbon that is sequestered by wetlands and sheltering a wide variety of flora and fauna. Obviously, in such a system, the cultivation methods are quite different from other wetland rice cultures. The area under DWR is shrinking heavily from over 2 lakh ha in 1990 to nearly 72000 ha in 2014 in the state. Weeds grow and offer tremendous competition to DWR as the crop is sown in the beginning of summer season, experience monsoon floods and harvested in the dry winter. The complex pattern of weed flora and their growth are the major reasons causing poor productivity of the crop. Unless the pattern of floristic changes of weed vegetation is understood, the effective and ecofriendly weed management strategy development is not possible. Hence, the DWR of Assam was systematically surveyed since 1991 and the survey data was computed to illustrate the patterns of changes in weed flora.

METHODOLOGY

One m^2 quadrats were used for random sampling in pre-flood, during flood and post flood stages of the DWR. Eight districts of the Brahmaputra valley were selected for the present analysis. The data were analyzed by following standard ecological to understand the species-area relationship with species time-lag is influenced by phyto-diversity components is also demonstrated.

RESULTS

The results revealed that, altogether 95 numbers of weed species were associated with the DWR throughout the Brahmaputra valley. Majority of weeds were dominant in the critical crop growth period and throughout the cropping season. Often, farmers sow autumn rice seeds mixed with DWR seeds. Grassy weeds dominated the crop-fields along with a few problematic broadleaved species; sedges during the early stage of the crop. A distinct shift in weed flora prior to flooding was recorded in recent years from *Paspalum* dominating situation before 2001 to current predominance of weedy rice in the North Bank Plain (NBP) zone, *Sacciolepis interrupta* prevailing situation in Dhemaji district, *Hymanachne acutigluma* and *Ludwigia linifolia* in Lakhimpur and *Melochia-Echinochloa* complex in Darrang district. Most of the early emerged weeds are being managed by the monsoon flood water and during this period *Paspalum-Sacciolepis* complex was observed to be the most commonly prevailing weed group. However, *Alternanthera philoxeroides* was one of the most problematic species in Jorhat, Kamrup and Barpeta districts. Sudden change in chemical, physical and microbial status of flooded soil including depletion of O_2, increase of N_2 and altering soil pH from acidic to neutral level might have helped in dramatic shift in weed vegetation pattern during inundation period. During this period, in spite of lesser weed species diversity than the pre-flood situation, weeds pose greater competition to the crop with the high weed density of *Echinochloa*, *Paspalum*, weedy rice and several other problematic aquatic weed groups. The weeds of exotic and indigenous origin have shown dissimilar relationships with environmental and landscape parameters in the entire 5-6 months cropping period because of their different historical background. The similarity study amongst the weed flora diversity of different situations revealed that Lower Assam districts were much similar to Darrang and Sonitpur. Crop fields of Jorhat and Sivasagar districts were in closely similar to those of the river Brahmaputra and their weed flora have depicted least similarity indices with that of NBP zone. The species-area curves showed increasing trend in Dhemaji, Lakhimpur, Sivasagar and Jorhat districts, where DWR fields had inundation water level varying from 100 to 300 cm. In contrary, the prospect of nesting more species with the increase of DWR area was much limited in Kamrup, Barpeta, Sonitpur and Darrang districts, where maximum inundation level varied from 70-100 cm. The habitat fragmentations coupled with higher degree of anthropogenic interventions might have caused increase in non-native weed species resulting in negative relation of nesting capacity of these ecological niches.

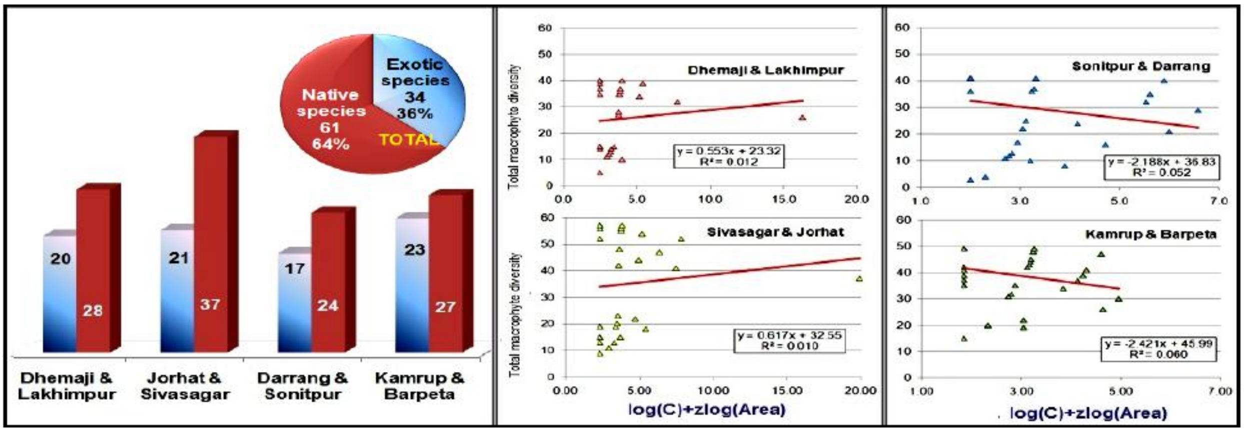

Fig. 1. Present status of native versus alien weed species in different DWR-growing areas and their impact on the nesting capacity of macrophyte diversity of these ecological niches

CONCLUSION

Distinct weed management strategies are essential at critical crop growth period as well as at inundated situations of DWR. The knowledge of habitat-specific weed flora composition is of high value for habitat conservation as well as optimal management of DWR.

Technical Session 4

Allelopathy, the current status and role in weed management

Allelopathy – A natural tool for weed management in field crops

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Weed management in field crops is an important practice for realizing optimum yield as weeds alone are responsible for one third of total estimated losses caused in production by pests (insects, diseases and weeds) in the world. Globally, the dependence on agrochemicals (fertilizers, herbicides and pesticides) has increased to meet the growing demand for agricultural products. These agrochemicals besides polluting the environment are also hazardous to human and livestock. Hence, use of allelopathy for weed management is one of the safe natural tools to overcome these problems through reduced use of herbicides or substituting them with natural products (plant and microbial products). Hence, allelopathy is the priority area of research in the world.

Allelopathy refers to "any direct or indirect inhibitory effect by one plant including microorganisms on another through the production of chemical compounds that escape into the environment" (Rice 1984). These allelochemicals includes aliphatic compounds, cynogenic glucosides, terpenoides *etc*.

Weed management by allelopathy in cereals

Post emergence application of sorghum + brassica + sunflower water extract each at 15 l/ha + bromoxynil + MCPA each at 50 g/ha in wheat has recorded significantly lower total weed density, total dry weight, higher no. of reproductive tillers and grain yield (21/m^2, 0.04g/m^2, 251.5/m^2 and 6.15 t/ha, respectively) when compared to weedy check (223/5m^2, 67.34g/m^{-2}, 138.5/m^2 and 4.55 t/ha, respectively) as reported by Javaid *et al*. (2010).

Abdul *et al*. (2012) reported that post emergence application of bispyribac-sodium at 30 g/ha in direct seeded rice has recorded significantly lower weed dry weight and higher grain yield which is on par with application of eucalyptus + mulberry + mango leaf extracts each at 18 l/ha + bispyribac-sodium at 15 g/ha compared to weedy check.

Weed management by allelopathy in pulses

Zahid *et al*. (2001) reported that three sorghum water extract sprays at 20, 30 and 40 DAS in mungbean has recorded significantly higher no. of pods per plant and grain yield (10.50 and 1.36 t/ha, respectively) when compared to weedy check (7.83 and 1.15 t/ha, respectively).

Faezeh *et al*. (2010) reported that three *Sorghum halepense* water extract spray at 15, 30 and 40 days after emergence has recorded significantly lower weed density, higher seed yield and oil content (188.7/m^2, 1.67 t/ha and 25.97%, respectively) when compared to weedy check (358.9/m^2, 1.17 t/ha and 25.91%, respectively).

Weed management by allelopathy in oilseed crops

Bhatti *et al*. (2000) reported that spraying of three sprays of sorghum water extracts at 15, 30 and 45 DAS has recorded significantly lower total weed dry weight, higher 1000 seeds weight and seed yield (5.47g/m^2, 2.752 g and 0.85 t/ha, respectively) when compared to weedy check (22.24 g/m^2, 2.22 g and 0.53 t/ha, respectively).

Inayat *et al*. (2009) reported that early post-emergence spray of sorghum + sunflower each at 18 l/ha + pre-emergence spray of pendimethalin at 413 ml/ha in sunflower has recorded significantly lower weed density at 70 DAS and higher seed yield (10.25/m^2 and 2.65 t/ha, respectively) when compared to weedy check (80.00/m^2 and 1.78 t/ha, respectively).

Weed management by allelopathy in commercial crops

Muhammad (2009) reported that spraying of ametryn + trifloxysulfuron at 375 g/ha + sorghum + sunflower water extracts each at 15 l/ha at four to six leaf stages of weeds in sugarcane has recorded significantly lower total weed biomass, higher stripped cane yield and net returns (24.72 g/m^2, 95.22 t/ha and 114850 Rs/ha, respectively) when compared to weedy check (340.88 g/m^2, 37.28 t/ha and 44825 Rs/ha, respectively).

Javaid and Zahid (2008) reported that pre-emergence spraying of S- metolachlor at 2.15 kg/ha has recorded higher reduction in *Cyperus rotundus* dry weight at 45 DAS and significantly higher seed cotton yield (86% and 2007 kg/ha, respectively) which was on par with spraying of sorghum water extract at 15 lit/ha + S- metolachlor at 717 g/ha (81% and 1.92 t/ha, respectively) when compared to weedy check (0% and 1.18 t/ha, respectively).

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Phytoherbicides: opportunities and research needs

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The present weed management in agriculture mainly depends on synthetic herbicides, which cause environmental pollution, restricted choice of succeeding crops and long residual activity. The herbicide industry is continuously searching for identification and characterization of most effective, economical and environmentally safer synthetic herbicides by screening large number of synthetic organic molecules, synthesizing analogs of patent herbicides, designing new herbicide molecules based on target site approach and screening of natural products for herbicidal activity. Screening of natural products has provided significant lead molecules for discovery of insecticides (pyrethroids), but not played significant role in herbicide discovery. The allelopathic properties of plants can be exploited successfully as a tool for the management of pathogens, insects and weeds. Large number of secondary metabolites/allelomones produced by the plants provides eco-friendly, diverse and challenging chemical structures. Some of them were act as potential herbicides with considerable crop selectivity and unique mode of actions (Vyvyan 2002),which could be directly used in the form of aqueous water extracts for weed management in organic and sustainable agriculture systems or chemistry of these products are used as lead molecules/templates for the development of new commercial herbicides.

The use of aqueous water extract of different plants such as sorghum, sunflower, maize, rice, sesame, eucalyptus and some of the weeds alone or in combination with reduced doses of synthetic herbicides are very effective and environmentally safe to manage the weeds in different crops. The concentrated sorghum water extract (*sorgaab)* at 12 l/ha along with reduced dose of pendimethalin 0.5 kg/ha as pre-emergence resulted in the lowest density of *Cyperus rotundus* L. and *Trianthema portulacastrum* L. in cotton (Cheema *et al*. 2002). Post-emergence application of *sorgaab* at 12 l/ha along with isoproturon 600 g/ha reduced the total weed dry weight by 91% in wheat and it was comparable with isoproturon 1000 g/ha (Jamil *et al.* 2005). Phytoalexins from the plants not only provide lead molecules or templates for new synthetic herbicides, but also useful in identifying the potential mode of action sites for herbicides. Structural modification of monoterpene, 1.8 cineole led to the development of synthetic herbicide cinmethylin, which is highly effective in controlling grassy weeds and some of the broad leaved weeds due to inhibition of mitosisin rice at 75g/ ha (Subramanyam *et al*. 2007). The mode of action of leptospermone, a triketone present in *Leptospermum scoparium* J.R. and G. Frost and *Callistemone citrinus* (Curtis) Skeels was similar to a synthetic herbicide, mesotrione to control the broad leaved weeds in corndue to inhibition of *p-hydroxy phenyl pyruvate dioxygenase*. Benzoquinones like sorgoleone, DIBOA and DIMBOA are well known natural allelochemicals may be considered as successful templates/lead molecules for designing new herbicide molecules. However, the success in the use of natural plant based herbicides is very limited due to complexity in chemical structures, limited stability in the environment, low herbicidal activity and difficulties in commercialization. There is a need to investigate rapid analytical techniques for identification and characterization of plant based herbicides, selectivity mechanisms to different crops including development of crop cultivars with effective alleleopathic potential through biotechnological approaches.

CONCLUSION

The aqueous water extracts of different plants alone or in combination with reduced doses of synthetic herbicides used to reduce the weed growth in organic and sustainable agriculture. Some of the secondary metabolites/ allelochemicals provides lead molecules or templates for new clues for the discovery of target sites and designing new herbicides. However, there is need to investigate the research gaps for the use of potential phyto-chemicals as natural herbicides.

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Isolation and identification of putative allelopathic compound in *Cymbopogon nardus*

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Cymbopogon nardus (L.) Rendle is perennial grass belonging to the family of Poaceae. This plant is widely distributed in tropical and subtropical areas of Southeast Asia. The plant has pharmacological properties such as antimicrobial, anti-inflammatory, antioxidant and mosquitocidal activities. It was indicated that the *C. nardus* whole plant extracts had strong allelopathic activity (Suwitchayanon and Kato-Noguchi, 2013). The present research focused on the determination of the allelopathic activity in leaf, stalk and root extracts of the plant and on the isolation and identification of the allelopathic compound in root extract of *C. nardus*.

METHODOLOGY

*C. nardus*was collected from Chiang Mai, Thailand in July 2012. The plant was separated into leaves, stalks and roots. Powderof those plant parts was separately extracted with 70% aqueous methanol for two days and re-extracted with cold methanol for one day. The two filtrates were combined, evaporated to dryness and dissolved with cold methanol. Biological activity was separately determined with six test plant species using four concentrations of the extracts.

Root extract was evaporated in rotary evaporator at 40°C to produce an aqueous residue. An aqueous residue was adjusted to pH 7 with 1 M phosphate buffer and partitioned with an equal volume of ethyl acetate. The residue of ethyl acetate phase was separated by columns of silica gel, Sephadex LH-20 and C_{18} cartridge. An active residue was finally purified by reverse phase HPLC (10 mm i.d. × 500 mm, ODS AQ-325; YMC Ltd, Kyoto, Japan) eluted at a flow rate of 1.5 mL/min with 70% aqueous methanol, detected at 220 nm and an active compound was eluted at the retention time of 58-61 min (as a white residue). An active compound was identified by^{1}H NMR. The biological activity of the compound was determined using cress and barnyard grass.

RESULTS

Aqueous methanol extracts of leaves, stalks and roots of *C. nardus* showed inhibitory activities on the growth of all test plant species. Leaf and root extract inhibited the growth of test plants at the concentration greater than 30 mg dry weight equivalent extract/mL, and stalk extract inhibited the growth of test plants at the concentration greater than 100 mg dry weight equivalent extract/mL. The concentrations required for 50% growth inhibition (I_{50}) on all test plants was in the range of1-25, 10-77, and r 4-23 mg dry weight equivalent extract/mL for of leaf, stalk and root extract, respectively. The results indicate that leaf and root extracts were more effectiveness than stalk extract. The difference in inhibitory effects of the extracts may be depended upon the volume of active compounds in each plant part (Shih *et al*. 2011). These results suggest that the effectiveness of the *C. nardus* extracts were test plant species-, extract-concentrations-, and plant-extract- part-dependent.

An active compound was isolated from the root extract of *C. nardus* and identified as *N*-octanoyl tyramine. The compound inhibited the growth of cress and barnyard grass at the concentration greater than 100 and 300 ìM, respectively. The growth of treated seedlings decreased with increasing of the compound concentrations. The I_{50}valuesof the compound on cress hypocotyl and root were 426 and 444 ìM, respectively, and on barnyard grass coleoptile and root were 1,428 and 449 ìM, respectively. Root exudation of allelopathic compounds has been reported in a number of plant species (Bertin *et al*. 2003). The present research suggests that root of *C. nardus* may produce growth-inhibiting compounds for the allelopathic activity and *N*-octanoyl tyramine may be responsible for this activity. It may also be possible that the compound may be released into the surrounding environment and affects the growth of another plant species.

CONCLUSION

An aqueous methanol extracts of *C. nardus* leaves, stalks and roots had inhibitory activities on the growth of all test plant species. An active compound in the root extract of *C. nardus* was isolated and identified as *N*-octanoyl tyramine. The compound had inhibitory activity on the growth of cress and barnyard grass. Thus, *N*-octanoyl tyramine may be act as an allelopathic compound produced by root of *C. nardus*.

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The potent allelopathic substances of cogongrass rhizome extracts

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Cogongrass (*Imperata cylindrica* (L.) Raeusch.) is ranked as one of the "100 of the world's worst invasive alien species" reported by the International Union for Conservation of Nature in 2000. This plant invades habitats of other plant species and forms monotypic expanses called the mega-grasslands. In order to clarify the mechanism of the successful invasion of cogongrass, allelopathy of cogongrass has been studied. Several secondary metabolites in leachate and extracts of cogongrass rhizomes were identified as putative allelopathic substances (Donald *et al*. 2013). However, available information about potent allelopathic substances of cogongrass rhizomes is limited. Thus, the objective of this study is isolation and identification of potent growth inhibitory substances of cogongrass rhizome extracts.

METHODOLOGY

The rhizomes of cogongrass were cut into small pieces and extracted with 70% aqueous methanol and filtered. The residues were extracted again with cold methanol and filtered. The two filtrates were combined and evaporated with a rotary evaporator at 40ºC. Aliquots of the extracts were dissolved into methanol and added to filter paper in Petri dish. Then, methanol was evaporated in a fume hood. The filter paper was moistened with 0.05% aqueous solution of Tween 20. The final assay concentrations of the extracts were ranged from 1 to 1000 mg dry weight equivalent extract/mL. These concentrations mean that the extracts obtained from 1 to 1000 mg dry cogongrass rhizomes were contained in 1 mL of the assay solutions. Cress (*Lepidium sativum* L.) seeds were arranged on the Petri dishes and incubated in the dark at 25ºC for 48 hours. Control seeds were incubated under the same condition described above without the extracts. After incubation, hypocotyl and root length of the cress were measured and compared to control. The extracts were then partitioned with water and ethyl acetate. The ethyl acetate fraction was separated by silica gel column. The biological activity of the fractions was determined using a cress bioassay. The growth inhibitory activities were found in two fractions obtained by elution with 70% ethyl acetate in *n*-hexane and methanol.

Purification of the inhibitory substance 1: The growth inhibitory active fraction eluted with 70% ethyl acetate in *n*-hexane was separated by Sephadex LH-20 column, reverse phase C_{18} cartridge and HPLC. The inhibitory activities of all fractions were determined by the cress bioassays after every separation steps. The most active fraction in each step was subjected to a subsequent separation step. The growth inhibitory substance1 was finally purified by HPLC and characterized by ^{1}H-NMR.

Purification of the inhibitory substance 2: The growth inhibitory active fraction eluted with methanol from silica gel column was separated by the same method described above. The inhibitory substance 2 was finally purified by HPLC and characterized by ^{1}H-NMR.The growth inhibitory activitiesof the inhibitory substance 1 and 2 were determined by the cress bioassays. Then, the0concentrations required for 50% growth inhibition were determined by a logistic regression analysis.0

RESULTS

At the concentration of 100 mg dry weight equivalent extract/mL, an aqueous methanol extract of cogongrass rhizomes inhibited the hypocotyl and root growth of cress by 19.1 and 36.6%, respectively. The growth inhibitory activity of the extract was concentration dependent.

Two growth inhibitory substances were isolated from the aqueous methanol extracts of cogongrass rhizomes. The inhibitory substance1 was characterized as abscisic acid. Abscisic acid inhibited the hypocotyl and root growth of cress by 12.7 and 40.3%, respectively, at the concentration of 1.0 ìM. The growth inhibitory activity of abscisic acid was concentration dependent. The concentrations of abscisic acid required for 50% growth inhibition on cress hypocotyls and roots were 0.30 and 0.52 ìM, respectively.

The inhibitory substance 2 was characterized as methyl caffeate. Methyl caffeate inhibited the hypocotyl and root growth of cress by 46.4 and 76.3%, respectively, at the concentration of 1.0 mM. The growth inhibitory activity of methyl caffeate was concentration dependent. The concentrations of methyl caffeate required for 50% growth inhibition on cress hypocotyls and roots were 0.97 and 1.3 mM, respectively.

CONCLUSION

Two potent inhibitory substances, abscisic acid and methyl caffeate, were isolated from the extracts of cogongrass rhizomes. The concentrations of abscisic acid and methyl caffeate required for 50% growth inhibition were ranged from0.30 - 0.52ìM and 0.97 - 1.3 mM, respectively. Those substances may contribute to the allelopathic property of cogongrass rhizomes.

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Optimized analytical techniques for extraction and separation of bioactive compounds from diverse plant types

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Bioactive compounds from plants provide unlimited opportunities for pharmaceuticals and natural agrochemicals development due to vast diversity of secondary compounds. Successful identification and development of natural products from plants necessitates a standard and integrated approach to screen compounds which aids in determination of dose response activity. We examined *Piperomia pellucid* (herb with fibrous root), *Cleome viscosa* (shrub with tap root), *Piper chaba* (climber) and *Artocarpus lakoocha* (tree). In *C. viscosa* plants, compounds were collected from 'Root Exudate Trapping System' made of Buchner funnel and conical flask, while compounds were collected from *P. pellucid* by a self-designed horizontal tube like glass ware with stopper and funnel at either ends. Compounds are extracted from stem and ground leaves of *P. chaba* and *A. lakoocha*. The basic sequential steps included grinding of plant parts, homogenization, vacuum filtration followed by liquid-liquid extraction in which bioactive compounds were fractionated into two major phases (ethyl acetate layer and aqueous layer). The extracts were further purified into a single pure compound by repetitive running through column and thin layer chromatography and finally subjected to spectral analyses. Four major compounds were recovered from *Piper chaba* and *Artocarpus lakoocha* with remarkable bioactivity. Lactam nonanoic acid with allelopathic properties was identified from *Cleome viscosa* and a new phenol glycoside with strong allelopathic activity was also isolated from *Piperomia pellucida*. These new extraction techniques will extend and enhance the usefulness of plants as renewable resources of valuable chemicals.

Allelopathic effect of siam weed on germination and growth of field crops

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Siam weed (*Chromolaena odorata*) is widespread in humid tropical regions specially southeast Asia and has become invasive in Bangladesh (Karim 2010). In India, siam weed causes yield losses up to 45% in several crops and 80% in forage production (Hills and Ostermeyer, 2000). It suppresses the growth of plants through allelopathic exudation like phenolics, alkaloid and amino acids (Rajangam 1997). With these views in mind, the present study was undertaken to evaluate the allelopathic effects of Siam weed on seed germination, development and growth of four field crops.

METHODOLOGY

Seeds of four crop species namely *Oryza sativa*, *Brassica napus*, *Cicer arietinum*, *Arachis hypogaea* were germinated with aqueous extracts of siam weed at different concentrations (4. 3.5, 2.5 and 0%) at the Seed Laboratory of Bangladesh Agricultural University, Mymen singh to see the impacts on seed germination and seedling growth. The germination percentage, root length and shoot length were recorded after 10 days of seed placement. Seedling dry weights were also recorded after being dried in an electrical oven for three days at 80^{0}C.

The overall effects on the growth of the crops was determined on the basis of average percent inhibition as below-

Average Percent Inhibition (API) = [G (%) + RL (%) + SL (%) + DM(%)]/4

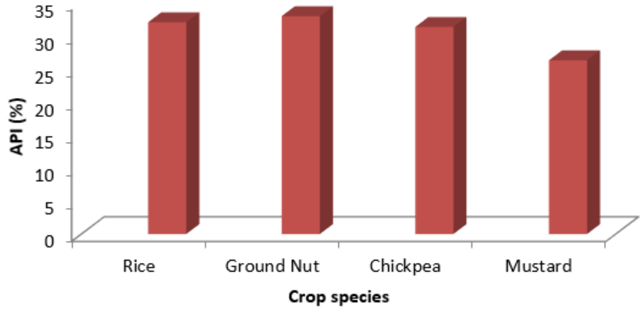
Where, G = percent reduction in seed germination, RL = percent reduction in root length, SL = percent reduction in shoot length, DM = percent reduction in seedling dry weight.

RESULTS

Average Percent Inhibition (API)

When API was calculated taking the average of all reductions caused in different plant characters of the crops it was observed that rice was mostly affected (API= 33.02) followed by groundnut (API= 32.95), chickpea (API= 31.32), and the lowest inhibition was marked in mustard (API = 26.27) due to allelopathic effect of Siam weed (Fig. 1). Onwugbuta (2001) observed that aqueous extract of Siam weed leaf at the concentration of 1 g/40 ml of water caused significant growth reduction of tomato. Gill *et al*. (2013) also found growth inhibitory effect of the weed on cowpea.

Among the plant parts, leaf of the weed was most inhibitory to the crop seed germination and seedling growth (API= 45.12) followed by root (API= 29.36) and stem (API= 22.92) (Fig. 2).



Among the plant parts, leaf of the weed was most inhibitory to the crop seed germination and seedling growth (API= 45.12) followed by root (API= 29.36) and stem (API= 22.92) (Fig. 2).

Fig. 1. Mean API (%) in four crop species due to allelopathic effects of Siam weed

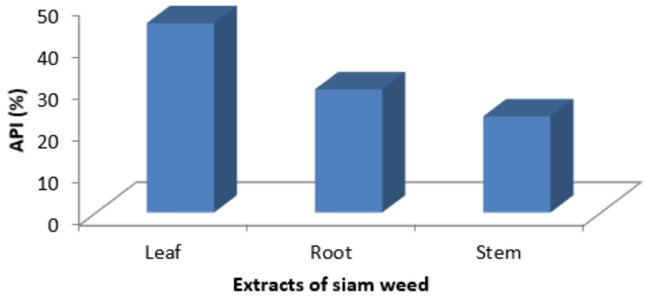


Fig. 2. Mean API (%) due to leaf, root and stem extracts of Siam weed in four crop species

CONCLUSION

Allelopathic effect of siam weed reduced the growth of crops namely rice, groundnut, chickpea and mustard significantly, API ranging from 26.3-47.3% and ground nut being the mostly affected crop. Leaf caused maximum inhibiton (API = 45.12%), while the stem showed the least inhibition effect (API = 22.92%). Siam weed leaf extract (4%) was enough to reduce the growth of the crops by about 50%. Invariably presence of siam weed in crop field or incorporation of leaves of siam weed in the fields must be avoided.

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The allelopathic nature of parthenium weed leaf litter: Will this change under a changed climate of CO_2 enrichment?

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Parthenium (*Parthenium hysterophorus* L.) is a highly suppressive weed species displacing many other plants, including native and introduced grass and broad-leaf pasture species (Adkins and Shabbir, 2014). Allelopathy is believed to play a key role in this growth suppression enabling the weed to quickly spread in to new habitats and gain dominance over native vegetation. This weed has been accidently introduced into Australia on two different occasions. The first introduction was at Toogoolawah in about 1945, but this biotype has not spread and remains restricted to only area few km^2. The second introduction was at Clermont in 1958, and this biotype has spread rapidly and now occupies over 600,000 km^2.Thus, the aims of the study were to 1) determine if the greater invasiveness of the Clermont biotype was due to a greater ability of its leaf litter to inhibit the growth of neighbouring plants and 2) whether this ability to suppress neighbouring plant growth may increase in the future under a changing climate of CO_2 enrichment.

METHODOLOGY

Seeds of two *parthenium* biotypes (Clermont and Toogoolawah) were germinated and when 2 cm tall transplanted into 14 cm diameter pots, containing UC potting compost. The pots were then watered daily to field capacity and growth took place under a 25/20°C (day/night) thermo-period with a 12/12 hour photoperiod (ca.800 ìmol/m^2/s), and either under an ambient CO_2 concentration of 380 ìmol/mol or an elevated CO_2 concentration of 550 ìmol/mol. After 50 days of growth leaves were collected from the two environments and biotypes, and dried in an oven at 35 ± 1°C for 4 days. The dried leaf samples were then broken into small pieces, well mixed and stored at 15 ± 1°C and 15 ± 3% relative humidity before being used 15 days later.

Autoclaved agar (0.75%; w/v; 5 mL) was added to the six wells of a series of multi-dish plastic plates (Coring Incorporated, USA). The dried *parthenium* leaf material (50 mg) was then added to the agar surface of three wells in each plate. On to these three wells, and the other three wells, was added a further 5 mL of liquid agar to form a sandwich (Fujii *et al.* 2003). Seven seeds of the various test species were placed onto the agar surface of each of the six wells per plate. After germination the seedlings were thinned to five and a second plate inverted over the first to provide a chamber into which the seedlings could grow. All plates were then incubated as described above. This sandwich box method (Fujii *et al.*, 2003) was replicated three times and in turn used to test four species [Curly windmill (*Enteropogon acicularis* L.) native, Cotton panic (*Digitaria brownii* L.) native, Lambs quarters (*Chenopodium album* L.) introduced and Liverseed grass (*Urochloa panicoides* P. Beauv.) introduced]. After 7 days of germination, the length of the seedling shoots and roots were measured. All data sets were then subjected to a general linear model with all species with a Minitab statistical package.

RESULTS

The root growth of all species was inhibited more than the shoot growth indicating a greater sensitivity of the roots to the presence of the leaf litter (Fig. 1). In addition, there was no significant difference between the impact of the two different biotypes and CO_2 concentrations on the level of inhibition (Fig. 1).

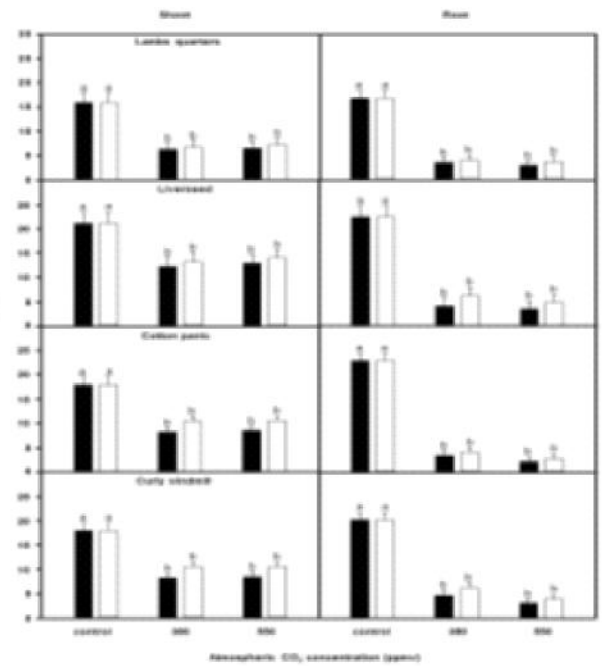

Fig. 1. The root and shoot growth of two introduced species (lambs quarters, liverseed) and two native species (cotton panic and curly windmill) when growing with 50 mg parthenium weed leaf litter produced by two biotypes(Clermont, Toogoolawah) under two CO2 atmospheres. Bars represent two standard errors of the mean. Means within species that do not share the same letter are significantly different from one another at *P > 0.05* level.

CONCLUSION

Seedlings of all species were significantly inhibited by the presence of small amounts of dried leaf material of *parthenium* weed indicating a strong allelopathic activity. There were no significant differences in the observed growth inhibition caused by litter from plants grown under an ambient as compared to an elevated CO_2 concentration, and there were no significant differences seen between the two biotypes indicating that the more invasive nature of Clermont was not due to its capacity of its litter to inhibit the growth of neighbouring plants.

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Technical Session 5

Weed management in organic farming systems including weeds use

Mechanised weed management in system of rice intensification for its potential to enhance productivity of irrigated rice

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Varietal improvement, including genetic engineering has not resulted in concrete solution for improved yield and nutrition. There is a challenge to develop novel technologies and production systems that allow rice production to be maintained or increased in the face of declining water availability. Growing rice by system of rice intensification (SRI) is a novel approach of rice cultivation which saves water and other inputs. System of rice intensification, developed in Madagascar, is a system approach to increase rice productivity with less external and inexpensive inputs. SRI method of cultivation is slowly gaining momentum all over the world including India. There is ample scope to increase productivity of rice by altering the environmental conditions that modify microclimate and soil conditions, which ultimately reflect phenotypic expression with the Genotype and Environment interactions. The System of Rice Intensification (SRI) is a holistic agro-ecological crop management technique seeking alternatives to the conventional high-input oriented agriculture, through effective integration of crop, soil, water and nutrient management.

METHODOLOGY

The filed experiments were conducted at 27different locations across the India such as Arundhatinagar, Aduthurai, Ari-Rajendranagar, Chatha, Coimbatore, Puducherry, Pantnagar, Gangavathi, Nawagam, Karjat, Ranchi, Pusa, Annamalai Nagar, Mandya, Siruguppa, Ambasamudram, DRR-Hyderabad, Chiplima, Raipur, Jagdalpur, Varanasi, Kapurthala, Malan, Karaikal, Maruteru, Patna and Umiam. The field experiment was establishment methods include four treatments in 11 locations during 2004 and 2005 *Kharif i.e*. Standard practice of planting (S1), System of rice intensification method (SRI) (S2), integrated crop management and modified mat nursery in transplanted rice (ICM) (S3) and Direct seeding with drum seeder (DS) (S4). Weed management in SRI consists of three treatments two times cono-weeding (10 and 20 DAT), Four times cono-weeding (10, 20, 30 1nd 40 DAT) and Herbicide pre-emergence butachlor at 1.5 kg/ha followed by one hand weeding at 10 locations in *Kharif* (2009 & 2010) and 7 locations in *Rabi* (2009-10 & 2010-11).

RESULTS

System of rice intensification performed better grain yield in all the locations in India over other methods of establishments. In Arundhatinagar, SRI recorded highest grain yield (8.59 t/ha) followed by Coimbatore (7.91 t/ha) and lest grain yield was at Chipilima (4.34 t/ha). Overall SRI recorded significantly superior grain yield (2.3%, 9.9% and 17.5%) over integrated crop management (ICM), standard practice of transplanting and direct seeding with drum seeder, respectively. The lowest grain yield observed at direct seeding with drum seeder at most of the locations (Table 1). Higher grain yield realized with SRI method may be due to the use of younger seedlings are transplanted at shallow depth and wider spacing, repeated cono-weeding during vegetative

Table 1. Effect of different establishment methods on grain yield of rice (t/ha) at across the India (mean of *kaharif*-2004&2005).

Treatment	ARI, R. Nagar	Sirugu -ppa	Mandya	Coim- batore	Aduthurai	Jagdal -pur	Karjat	Nawagam	Malan	Chiplima	Arundhati -nagar	Mean
S1	5.76	5.63	5.58	6.17	4.73	5.67	6.24	5.99	5.54	4.73	5.61	5.60
S2	6.61	4.96	6.31	7.91	6.50	5.67	6.69	5.88	4.78	4.34	8.59	6.22
S3	6.03	4.85	6.14	7.05	6.56	5.71	6.65	5.77	4.89	5.11	8.09	6.07
S4	4.49	5.70	5.91	5.82	4.11	4.97	5.78	5.30	4.69	4.15	5.54	5.13
Mean	5.72	5.29	5.99	6.74	5.48	5.51	6.34	5.74	4.98	4.63	6.96	5.76
LSD (P= 0.05) 0.557												

S_1 - Standard practice of planting; S_2 - System of rice intensification method (SRI); S_3 - Integrated crop management and modified mat nursery in transplanted rice (ICM); S_4 - Direct seeding with drum seeder

Table 2. Effect of weed management practices on grain yield of rice under system of rice intensification in India (mean of *Kharif* 2009 & 2010)

Treatment	Aduthurai	ARI-Rajendranagar	Chatha	Coimbatore	Puducherry	Pantnagar	Gangavathi	Karjat	Ranchi	Pusa	Mean
T_1	7.02	5.81	4.05	5.89	4.69	4.80	4.10	5.57	6.08	7.66	5.57
T_2	7.24	5.91	4.49	6.58	4.91	5.19	4.25	6.19	6.14	8.05	5.90
T_3	5.45	6.00	3.40	6.13	4.67	4.00	4.82	6.15	5.56	6.57	5.28
Mean	6.57	5.91	3.98	6.20	4.76	4.66	4.39	5.97	5.93	7.43	5.58
LSD (P=0.05) =0.417											

Table 3. Effect of weed management practices on grain yield of rice under system of rice intensification in India (*Rabi*, 2009 -2010)

Treatment	Aduthurai	Arundhati Nagar	Annamalai Nagar	Coimbatore	Karjat	Mandya	Puducherry	Mean
T_1	6.85	6.80	1.73	4.59	4.23	4.14	4.61	4.71
T_2	7.44	6.73	2.52	5.87	5.13	5.12	5.36	5.45
T_3	4.58	7.30	3.63	5.55	4.71	4.67	4.05	4.93
Mean	6.29	6.94	2.63	5.34	4.69	4.64	4.67	5.03
LSD (P = 0.05) =0.899								

T1 - 2 times cono weeding (10 and 20 DAT); T2 - 4 times cono weeding (10, 20, 30 1nd 40 DAT); T3 - Herbicide pre-emergence butachlor at 1.5 kg/ha followed by one hand weeding growth, soil was kept well aerated and rich with diverse microorganisms, which preserves a potential for more tillering, rooting and dry matter production.

Four times cono-weeding at 10, 20, 30 and at 40 DAT recorded superior grain yield in all the locations during both *Kharif* and *Rabi* seasons (5.90 & 5.45 t/ha) over herbicide pre-emergence butachlor at 1.5 kg/ha followed by one hand weeding (5.28 and 4.93 t/ha) and 2 times cono weeding at 10 and 20 DAT (5.57 and 4.71 t/ha), respectively. Whereas in *Kharif* season two times cono-weeding at 10 and 20 DAT performed better grain yield than herbicide application but in *Rabi* season Herbicide pre-emergence butachlor at 1.5 kg/ha followed by one hand weeding shown higher grain yield than 2 times cono weeding at 10 and 20 DAT.

Overall the effect on grain yield of rice indicated that superiority infourtimes cono-weeding (10, 20, 30 and 40 DAT) as compared to two times cono-weeding (5.7% less grain yield) and herbicide application (11.8% less grain yield) during *Kharif* season (Table 2). In rabi season there was no significant yield difference but times cono-weeding (10, 20, 30 and 40 DAT) recorded higher grain yield (5.45 t/ha) followed by herbicide application (4.93t/ha) and lowest grain yield observed at 2 times cono-weeding (4.71 t/ha) (Table 3). Higher numbers of cono-weeding helps to weeds are buried inside the soil and minimized the weed competition besides it improving soil aeration, root development, nutrient absorption and more number of tillers which favoured the crop growth and resulted in higher grain yield.

CONCLUSION

SRI recorded significantly higher grain yield (6.22 t/ha followed by integrated crop management (ICM) (6.07 t/ha), standard practice of transplanting (5.60 t/ha) and direct seeding with drum seeder (5.13 t/ha). The effect of cono-weedings indicated the superiority of 4 times cono weeding (10, 20, 30 and 40 DAT) followed by 2 times cono weeding (5.7% less) and herbicide application (11.8% less) during *Kharif* season. Based on multi-location testing over a decade, indicated that SRI has the potential to enhance the productivity of the rice with reduced inputs in different agro-ecological situation and soil types across the country with reduction in drudgery of weeding in rice. There is need to economies the mechanical weeding operations and development of cost effective efficient motorized weeders for popularization of the SRI in large scale in India.

Interference of weed competition in rice fallow cotton

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Rice-fallow cotton cultivation is a unique system, wherein the cotton seeds are dibbled amidst the rice stubbles without tilling the soil to effectively utilize the residual soil moisture. Cotton faces a severe competition from the early emerging weeds and the weeds that are already present in rice field at the time of harvest with yield reduction up to 85% (Latha 2005). Weed management during the early stages of cotton growth is more important. Hence, it is necessary to find out the critical period of crop weed competition to make weed control more effective and economical.

METHODOLOGY

The field experiment was conducted during the summer season of 2007 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal. The soil of the experimental field was sandy clay low in nitrogen and high in phosphorus and potassium. Twelve treatments consisting of weed free and weedy periods at 20, 40, 60, 80 and 100 DAS and at harvest along with a weedy and weed free check were arranged in randomized block design with 3 replications. The cotton variety'MCU7' was sown at 15 kg/ha with a spacing of 60 × 30cm. The recommended dose of 60 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha was applied. Half of nitrogen was applied at sowing and remaining half was top dressed 41 days after sowing (DAS).

RESULTS

The major weed flora of the experimental field were *Cyperus rotundus* (sedge after 40 DAS), *Echinochloa colona L., Leptochloa chinensis L.* (among grasses), *Trianthema portulacastrum, Rotala densiflora, Eclipta alba and Phyllanthus maderaspatensis* (broad leaf weeds).

The highest seed cotton yield (2676 kg/ha) was obtained in weed free up to 80 DAS which was on par with that in weed free up to 100 DAS (2393 kg/ha), weed free up to 60 DAS (2336 kg/ha) and weedy up to 20 DAS (2342 kg/ha). The seed cotton yield increased with increase in the duration of weed free period. However, maintaining the field weed free beyond 80 DAS considerably reduced the seed cotton yield due to lower boll setting percentage. Weeds, when left unchecked until harvest, reduced the seed cotton yield by 96.5%. The loss in yield was proportional to the duration of weed infestation. The yield declined at the rate of 6.019 kg/ha for every kg of weed dry matter produced. The loss in the yield decreased with increase in the duration of weed free condition during the initial period of crop growth.

Table 1. Effect of weed free and weedy periods on seed cotton yield and yield attributes of rice-fallow cotton

Treatment	Seed cotton yield (kg/ha)	No. of bolls/ plant (At harvest)	Weed index (%)
Weedy for 20 DAS	2342	14.6	12.5
Weedy for 40 DAS	1173	10.9	56.2
Weedy for 60 DAS	462	8.1	82.7
Weedy for 80 DAS	266	5.9	90.1
Weedy for 100 DAS	131	2.6	95.1
Weedy up to harvest	94	1.2	96.5
Weed free up to 20 DAS	353	4.5	86.8
Weed free up to 40 DAS	2058	13.9	23.1
Weed free up to 60 DAS	2336	17.1	12.7
Weed free up to 80 DAS	2676	21.8	0.0
Weed free up to 100 DAS	2393	17.5	10.6
Weed free up to harvest	2308	17.3	13.7
LSD (P=0.05)	352	1.6	-

CONCLUSION

The critical period crop-weed competition in rice-fallow cotton was found to be between 20 and 60 DAS. Maintaining the field weed free up to 80 DAS resulted in the highest seed cotton yield and maximum profit. However, maintaining the field weed free beyond 80 DAS resulted in significantly lower yield due to lower boll setting percentage.

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Weed dynamics and rice productivity under organic conservation tillage practices in rice-vegetable pea cropping system

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Weed infestation is a major challenge to sustain the rice productivity especially under organic management conditions. Further, intensive tillage practices may also aggravate weed problems in hilly production system. Weeds can reduce rice yield varying from 20 to 80 per cent if not controlled even at early stage. Farmers of the state mainly grow transplanted puddled rice with poor agronomic management practices. Hence, crop yields are low, however, the quantum of resources used per unit of production is very high. Tillage practices contribute greatly to the labour cost in modern intensive agriculture in any crop production system resulting in lower economic returns. Acute shortage of water, labor and energy resources, along with faulty crop management practices and the adverse effects of conventional tillage on the soil health, as well as declining of profitability are the major challenges towards the resource poor farmers of the state. Hence the present investigation was undertaken.

METHODOLOGY

A fixed plot field experiment was started during *kharif* season of 2014 at ICAR Sikkim Centre situated at a latitude of 27° 32' N and longitude of 88° 60' E, altitude of 1350 m. However, the experiment was maintained under organic conservation tillage practices since 2013 in both *kharif* and *Rabi* seasons. The experiment was laid out in split-plot design, assigning three tillage practices, *viz*, conventional (CT), reduced (RT) and no till (NT) in main plots and four recommended dose of nitrogen organic sources *viz.*, control (FP), 100% N through farm yard manure (FYM) + biofertilizer (BF), 100% N through vermin-compost (VC) + BF and 50% N through FYM + 50% N through VC + BF to sub-plots. All the treatments were replicated thrice. Field was prepared as per the treatment for planting of rice. The crop was grown as per the recommended package of practices of the region and harvested in first fortnight of November. Observation on weed dynamics and crop productivity was recorded as per the standard procedures.

RESULTS

The results (Table 1) revealed that the weed dynamics significantly affected by tillage practices at all the stages of crop growth (30 and 60 DAP).Amongst the tillage practices, minimum population of all weed flora (grasses, sedges and broadleaved) was recorded with no till at 30 DAP. This leads to about 16.9, 11.6 and 23.1% reduction in grasses, sedges and broadleaved weeds over the conventional practices, respectively. However, at 60 DAP reverse scenario of weed dynamics has been observed in grasses and broadleaved. Significantly lower weed population (63.5 and 23.8 nos. m^2) was recorded with conventional in grasses and broad leaved. However, organic sources of nutrient failed show any significant effects on weed population at both the growths stages of rice.

Table 1. Effect of tillage practices and organic nitrogen sources on weed density and productivity of rice

Treatment	Weed density (no./m^2)						Grain yield (t/ha)	B:C ratio
	Grasses		Sedges		Broadleaved			
	30 DAP	60 DAP	30 DAP	60 DAP	30 DAP	60 DAP		
Tillage practices								
Conventional tillage (CT)	7.25 (52.3)	8.00 (75.4)	6.93 (47.5)	7.70 (59.0)	4.91 (23.7)	4.92 (23.8)	3.25	1.88
Reduced tillage (RT)	6.98 (48.4)	8.41 (70.3)	6.77 (45.4)	7.30 (52.9)	4.27 (17.9)	5.19 (26.7)	3.32	2.18
No Tillage (NT)	6.20 (38.8)	8.71(63.5)	6.21 (38.2)	6.96(48.1)	3.99 (15.5)	5.38 (28.7)	3.41	2.47
LSD (*P*=0.05)	0.25	0.30	0.33	0.33	0.51	NS	0.08	0.09
Organic nitrogen sources								
Farmers practice	6.96 (48.2)	8.38 (69.9)	6.60 (43.3)	7.35 (53.7)	4.49 (20.0)	5.07 (25.3)	2.71	2.06
100 % RDN through farm yard manure (FYM)	7.00 (49.2)	8.56 (72.9)	6.80 (45.8)	7.41 (54.8)	4.52 (20.1)	5.36 (28.3)	3.26	2.47
100 % RDN through vermicompost (VC)	6.41 (40.9)	8.25 (67.8)	6.50 (41.9)	7.22 (52.9)	4.19 (17.3)	5.01 (24.9)	3.55	1.77
50% RDN (FYM) + 50 % RDN vermicompost (VC)	6.87 (46.9)	8.29 (68.3)	6.64 (43.8)	7.30 (53.0)	4.35 (18.7)	5.22 (26.7)	3.79	2.41
LSD (*P*=0.05)	NS	NS	NS	NS	NS	NS	0.15	0.14

Data subjected to square root (x + 0.5) transformation; Values in parentheses are original

Grain yield was significantly influenced by different tillage and organic nitrogen sources and the highest yield was recorded with NT (3.41 t/ha) fallowed by RT (3.32 t/ha) and lowest in CT (3.25 t/ha). With regard to organic sources of nutrients, application of 50% FYM + 50% VC + Biofertilizer recorded significantly maximum grain yield (3.79 t/ha) over other organic sources. Ultimately it resulted in higher B:C ratio.

CONCLUSION

Thus it is concluded that no tillage with recommended dose of nitrogen substituted in 1:1 ratio of FYM and VC + BF (50% FYM + 50% VC + biofertilizer) was most effective for reducing weed pressure and enhancing rice productivity under organic management condition of Sikkim Himalayas.

Weed management practices in maize under organic farming in rainfed hill-ecosystem

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Maize (*Zea mays* L.) is predominant rainfed crop in the upland ecosystem of North Eastern Region (NER) of India (Das *et al*. 2010). Rainy season maize suffers from severe weed competition due to slow initial growth and wide spacing. In organic farming, the weeds problems are further high mainly due to application of organic manure, mulches, biomass which exacerbates the weed multiplication and growth. Thus, it is necessary to devise organic system of weed control comprising of cultural, mechanical, biological and physical practices to manage weeds without synthetic herbicides and chemicals which promote weed suppression, rather than weed elimination. Hence, the present investigation was undertaken.

METHODOLOGY

Field experiments were conducted in the mid hills of Meghalaya under terrace condition during *Kharif* seasons of 2008-09 to 2010-11. The treatments consisted of mechanical weeding at 20 days after sowing (DAS) + hand weeding (HW) once after earthing up at 45 DAS, mulching with fresh *Chromolaena* at 10 t/ha, aqueous leaf extract (10%) spray of *Lantana camara* and *Pinus kesiya* (pine) needle, HW twice (20 and 45 DAS), aqueous leaf extract spray of lantana and pine needle + HW once at 35 DAS, soybean green manuring + HW once after earthing up (45 DAS), weed free check (HW at 10, 25, 35, 45 and 55 DAS) and weedy check. One row of soybean was grown in between two rows of maize as green manure and incorporated into the soil at 30 days after germination at the time of earthing up. Data on maize yield and weed growth were recorded.

RESULTS

The number of seeds/cob of maize were the highest under weed free check, however it statistically at par with mulching (Table 1).Three years average grain yield of maize was maximum under fresh *Chromolaena* mulching followed by HW twice at 10 DAS & 40 DAS and soybean green manure incorporation in situ + HW once. All the weed management practices were effective in suppressing total weed density and dry matter as compared to weedy check. HW twice, soybean green manure incorporation + HW once and mechanical weeding (20DAS) + HW once (after earthing up) was also found effective in reducing weed population to the extent of 72, 67 and 68% in 30 DAS and 77, 78 and 80% in 60 DAS as compared to weedy check, respectively. In general, weed dry weight was found higher at 30 DAS compared to 60 DAS in all the treatments except weedy check and aqueous leaf extract spray of lantana & pine which may be due to suppression of weed growth by maize canopy at later growth stages. Pooled weed control efficiency was ranged from 71.33-91.97 and 31.59-72.90 % in 30 & 60 DAS respectively. Among all the treatments, aqueous leaf extract spray of lantana + HW twice was recorded maximum WCE compared to other treatments.

Table 1. Weed growth, weed control efficiency and yield of maize as influenced by different weed management practices

Weed management practices	Seeds /cob in maize	Maize yield (t/ha)	Population density (no./sqm) of weed		Dry weight (g/m^2) of weed		Weed control efficiency (%)	
			At 30 DAS	At 60 DAS	AT 30 DAS	At 60 DAS	AT 30 DAS	At 60 DAS
Mechanical weeding (20 DAS) + one hand weeding (HW) after earthling up	261.6	3.33	158.9	75.0	941	4.2	86.1	94.8
Muching with fresh *Chromolaena biomass* (after earthling up) at 10 t/ha	281.5	3.87	225.5	89.7	12.9	17.5	74.6	78.6
Aqueous leaf extract (10%) spray of lantana and pine	263.8	2.87	359.3	235.3	26.0	44.6	48.6	34.2
Hand weeding twice	281.0	3.64	145.5	87.7	7.2	4.2	85.9	94.9
Aqueous leaf extract spray of lantana and pine + HW once	268.1	3.54	185.3	91.4	11.7	6.7	76.9	91.7
Soybean GM incorporation in situ + HW once	280.5	3.64	155.8	84.3	10.5	4.9	79.2	94.0
Weed free Check	284.8	3.61	4.8	2.0	0.8	0.2	98.4	99.8
Weedy check	244.3	2.65	493.4	392.2	50.7	81.6	86.1	94.8
LSD (P=0.05)	5.23	0.39	-		-		-	

DAS: Days after sowing; GM: Green manure

CONCLUSION

It can be concluded that mulching with weed biomass such as fresh *Chromolaena* (after earthing up) and soybean green manuring in maize + HW once are the recommendable options for sustainable maize production under high rainfall hill ecosystem of North East India.

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Removal of malachite green dye by *Parthenium hysterophorus*: safe strategy for weed management

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Every manufacturing industry uses dye to colour their products, but unfortunately residual and unspent dyes are discharged without any proper treatment directly into the water bodies (Papinutti *et al.* 2006). Dyes are one of the major water pollutants which adversely affect agriculture and environment as these are synthetic chemicals which may contain some toxic components such as metals and chloride. Thus, removal of dye from the industrial waste effluent is one of the challenging tasks for the environmentalists. *Parthenium hysterophorus* is unwanted weed and its huge biomass is available round the year. This weed can be used for the treatment of industrial effluent due to its dye adsorption capacity. The aim of the present work was to study the adsorption capacity of *Parthenium* weed for the removal of malachite green dye from aqueous solution under different experimental conditions.

METHODOLOGY

The healthy plants of *Parthenium hysterophorus* were collected from the road sides and waste lands near Amity University campus, Noida and leaves of *Parthenium* weed were dried in shade for 72 hours. Then the dried leaves were powdered in grinder and leaf powder was used as adsorbent. An aqueous solution of malachite green dye (100 PPM) was prepared by using distilled water and the pH was measured. Batch experiments were conducted to study the effect of different parameters i.e. pH, exposure time and amount of adsorbent for the removal of malachite green dye. An aliquot of 100 ml of dye solution was treated with different amount of *Parthenium* leaf powder such as 0.5g, 1.5g and 2.5g at different pH and interval of 30, 60 and 90 minutes respectively. The optical density was taken at 617 nm by using UV/VIS spectrophotometer. The percentage removal of dye was estimated by using the following formula:

Removal efficiency (%) = $(C_o - C_e/C_o) \times 100$

Where C_o = initial concentration of dye (mg/l)

C_e = final concentration of dye (mg/l)

RESULTS

In the present study, *Parthenium* leaf powder was used as adsorbent and percentage removal of malachite green dye was analyzed at different pH and time with different amount of adsorbent. Maximum removal (82%) of malachite green dye was observed at pH 5.8after 60 minutes of exposure of 2.5g dry leaf powder of *Parthenium hysterophorus* per 100 ml of aqueous solution. Increase in adsorption of malachite green dye with increase in adsorbent amount can be attributed to increased adsorbent surface area and availability of more adsorption sites (Mulugeta and Lelisa, 2014). Thus, this new method can be used widely due to its dual significance as it is useful for the management of*Parthenium hysterophorus* weed as well as it removes dye from aqueous solution.

Table 1. Removal of malachite green dye by different amount of leaf powder of *Parthenium hysterophorus* at pH 5.8after 60 minutes of exposure time

Sr.no	Amount of adsorbent* (g)	Removal of malachite green dye (%)
1.	0.5	43
2.	1.5	61
3.	2.5	82

CONCLUSION

The present study clearly indicates that the treatment of malachite green dye by using leaf powder of *Parthenium* weed is a simple, cost-effective and eco-friendly technology as it has significant potential of reducing colour. The data of the present investigation may be useful in fabrication of new economically viable treatment process by utilization of batch tank flow reactors for the removal of dye from industrial waste effluent. This serves as alternate strategy to contain the menace of *parthenium*.

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Effects of soil types on efficacy of S-metolachlor-treated oil palm frond mulch on inhibition of herbicide-resistant biotypes of goosegrass

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Various herbicide-resistant biotypes of goose grass (*Eleusine indica*) have been reported worldwide (Heap 2015), including Malaysia (Chuah and Ismail, 2010) due to the long term and heavy reliance on single herbicide for weed control. Goose grass has been documented to develop resistance to herbicides such as glyphosate, fluazifop, paraquat and glufosinate. This study revealed that a combination of chemical and physical methods through oil palm frond mulch treated S-metolachlor provided inhibition of herbicide-resistant biotypes of goose grass, depending on soil types.

METHODOLOGY

A greenhouse study (85%relative humidity, 35-38°C temperature, and 12 h photoperiod at a light intensity of 800-1000 µmol/m^2/s^1) was conducted during August of 2014 at the School of Food Science and Technology, University of Malaysia Terengganu, Malaysia. The treatments (combinations of S-metolachlor + oil palm frond residue) consisting of 3 rates, 8.0+ 1.0, 12 + 1.5 and 16 + 2.0 (g/ha + t/ha) and 2 soil media, silt loam (21.8% clay, 52.6% Silt, 25.6% sand, 1.6% organic carbon, 10.3 meq/100g CEC, pH 4.0) and sandy loam (3.2% clay, 30.0% Silt, 66.8% sand, 2.7% organic carbon, 5.2 me q/100g CEC, pH 5.5)were arranged in a complete randomized design with five replications. Each cup, filled with 75g of soil, was placed in trays and water was applied from the bottom of the cup for irrigation. Twenty seeds of glyphosate or fluazifop-resistant biotypes of goose grass were sown evenly on the soil surface a day before the application of treatments. Number of seedling emergence was counted while shoot fresh weight of goose grass seedlings was measured 30 days after treatment (DAT).The data were tested for the normality and homogeneity of variance before being subjected to two-way analysis of variance, ANOVA (SPSS version 16). Arcsine square root and log transformations were performed on percentage data of emergence and shoot fresh weight for the glyphosate-resistant biotypes, respectively, followed by Tukey's test for means comparison at 5% level of significance. ED_{50} values were estimated manually by plotting graphs.

RESULTS

S-metolachlor-treated oil palm frond mulch rate-by-soil-series interaction was significant forglyphosate, and fluazifop-resistant biotypes of goose grass. In general, both resistant biotypes of goose grass grown in sandy loam soil were more susceptible to S-metolachlor-treated oil palm frond residues as compared to those grown in silt loam soil. The treatment with the lowest rate 8.0 g/ha S-metolachlor + 1.0 t/ha oil palm frond mulch showed the least phytotoxic activity when treated on both resistant biotypes regardless of the soil media, but a great inhibitory effect was observed as the application rate was increased to 16.0 g/ha S-metolachlor + 2.0 t/ha oil palm frond mulch. The rate that gives 50% inhibition (ED_{50}) of the seedling emergence for glyphosate or fluazifop-resistant biotypes of goose grass in silt loam soil were ranged from 13 to 15 g ai/ha S-metolachlor + 1.6 to 1.9 t/ha oil palm frond mulch. A greater suppressive effect was found in sandy loam soil where lower ED_{50} values were observed, 9 to 11 g/ha S-metolachlor + 1.2 to 1.4 t/ ha oil palm frond mulch. Same results were observed in seedling growth where 6 to 7 g/ha S-metolachlor + 0.8 to 1.0 t/ha oil palm frond mulch was needed in sandy loam soil, as compared to 12-14 g/ha S-metolachlor + 1.5 to 1.8 t/ha oil palm frond mulch in silt loam soil to achieve ED_{50}. Sandy loam soil which has lower clay content (Westra *et al*. 2014) and cation exchange capacity might result in more S-metolachlor molecules available for plant uptake, thus leading to a better suppression of goose grass emergence and seedling growth. Moreover, higher pH level in sandy loam soil may reduce the herbicide sorption which increases the bioavailability of herbicide for plant uptake (Grey *et al.* 1997).

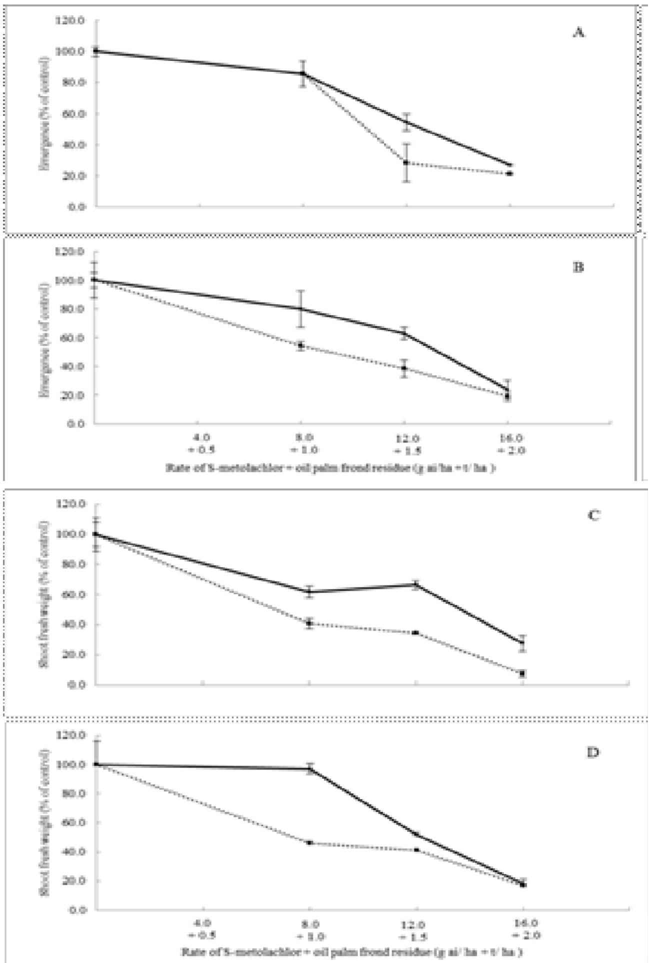

Figure 1. Pre-emergence application of S- metolachlor + oil palm frond residue on seedling emergence and shoot fresh weight of glyphosate (A and C), and fluazifop (B and D)- resistant biotypes of goosegrass in silt and sandy loam soil. Vertical bars represent standard deviation (SD) of the mean

CONCLUSION

It can be concluded that S-metolachlor + oil palm frond mulch at a rate of 16 g/ha + 2.0 t/ha provides great inhibition of glyphosate and fluazifop-resistant biotypes of goose grass in both silt loam and sandy loam soil.

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Technical Session 6

Innovative weed management technologies

Searching for potential future solutions for managing aquatic weeds

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A number of floating, emergent and submerged aquatic weeds have colonized Australian and New Zealand waterways, assisted mainly by human activities. In most cases, excessive growth of aquatic weeds has significant 'triple bottom line' impacts: (a) environmental (reducing biodiversity); (b) economic (increased costs of control), and (c) social (reduced aesthetic values and recreational opportunities of water bodies and waterways). Managing aquatic species requires a strategic approach, as well as timely, tactical interventions. The strategic approach involves direct action, as well as indirect action.. Some key principles behind a strategic approach include: (a) planning and rationalizing management actions- includes acting locally while thinking more upstream (sources of weeds) and downstream (impacts of control action); (b) coordination of actions across catchments (inter-agency co-operation); (c) prevention of entry, early detection of infestations and eliminating the problem; (d) integrating control methods (manual, mechanical, chemical, biological and cultural); (e) training and education- community, aquarium, nursery, shipping industries and stakeholders (weed officers, contractors); and (f) a commitment to long-term ecosystem management. In most cases, once aquatic plants become established in a waterway, eradication is impossible, because even the smallest viable vegetative fragment can re-establish a population. Left uncontained, aquatic weeds often fully colonize all available habitats, within a short period of time.

Weed control techniques used for managing aquatic weeds in Australia and New Zealand are discussed, along with their strengths, weaknesses and costs. Most non-chemical methods are not cost effective, and are of limited value in controlling many species. In contrast, aquatic herbicides offer more promise for cost-effective control, although eradication is still not an option, due to inadequate plant exposure and uptake. Several case studies from Australia are discussed, in which Diquat-Hydrogel[â] provided cost-effective control of large infestations of submerged aquatics: Hydrilla [*Hydrilla verticillata* (L.f.) Royle]; Hornwort (*Ceratophyllum demersum* L.); Egeria (*Egeria densa* Planch.); Sago Pondweed (*Potamogeton pectinasus* L.); Naiads (*Najas tenuifolia* R.Br. and *Najas marina* L.) and Charophytes – *Chara* L. and *Nitella* Agardh. Diquat causes a rapid die-off of the shoot portions of the plant it contacts; however, it is not effective on roots, rhizomes or tubers, requiring subsequent applications. Diquat will bind to particulate and dissolved organic matter, which restricts its use in some water bodies. Our research confirms that diquat effects are enhanced by tank mixing with copper compounds. Recent trials in shallow ponds indicate that dense aquatic weed infestations could be reduced by approximately 50-70% with one or two treatments of Diquat-Hydrogel[â] with Copper. However, in deeper and larger lakes, control has been variable, largely due to inactivation by particulate matter.

Some of the major challenges for strategic aquatic weed management area) balancing the social and economic needs with environmental needs (For instance, are all aquatic weeds/ plants in waterways to be deemed equally 'bad'?); b) cost-effective control (Herbicides are the least expensive option), c) integrating the limited number of methods available (*i.e.* Reducing water clarity or increasing water levels will reduce submerged species); d) more effective and safe methods of control, e) minimising potential adverse environmental impacts of recurrent control action on waterways (Reducing reliance on herbicides; increasing the effectiveness of existing biological control agents and searching for newer ones); f) preventing wider spread of existing infestations into un-infested areas (Requires increased allocation of resources for implementing weed management plans); and g) continuing the global spread of non-indigenous plants (Many more potentially problematic species are likely to enter the Asian-Pacific Region, including Australasia and Oceania through global trade and transport).

DISCUSSION AND CONCLUSIONS

In managing aquatic weeds, any opportunity for integration of control methods must be adopted. This may include: (a) manual removal; (b) Use of physical barriers to arrest spread via flowing water; (c) detention basins and wetlands to mitigate nutrient flows from catchments; and (d) Riparian zone rehabilitation with competitive natives. The search continues for novel biological control agents for several aquatic weeds, but the speed of progress has declined with reduced funding. In the short-term, aquatic herbicides can assist in managing some of the problems. However, increased research is needed to optimize: (a) multiple treatments/split-applications; (b) integrate available methods and 'site-specific' treatments, targeting a desired outcome; (c) delivery systems (*i.e.* gel-forms with biodegradable, inert compounds). It may also be advisable to register compounds, such as Endothal, Triclopyr 3A and Fluridone, to assist Asian-Pacific countries to better manage aquatic weed problems.

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CRIJAF Nail weeder an innovative tool for weed management: Farmers' experience

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Major types of weed species in jute (*Chorchorus olitorius* and *C. capsularis*) prevalent at farmer's fields are sedges (*Cyperus rotundus, Cyperus difformis* and *Cyperus compressus*), grasses (*Bracharia ramosea, Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Echinochloa colona, Eleusine indica*) and broad leaved (*Amaranthus viridis, Cleome viscosa, Digera arvensis, Phyllanthus niruri, Portulaca oleracea, Trianthema portulacastrum*). It has been reported that if weeds are not managed properly, loss of yield can be upto 40-70%. Conventionally, jute growers follow two manual weedings (20-25 DAS and 35-40 DAS) preferably by khurpi, blade hoe or wheel hoe. It costs around 35% of the total cost of cultivation and affects the profitability. Small proportion of them also goes for herbicide application *i.e.* Quizalafop ethyl, Butachlor or Pretilachlor subject to availability and soil moisture condition. ICAR-CRIJAF, Barrackpore has developed CRIJAF Nail weeder that can economize the cost of cultivation. It is able to reduce the labour requirement ~~of~~ for weeding by 65-80% (Ghorai *et al.* 2010 and Annual Report DARE 2010-11).

METHODOLOGY

The present study was conducted during 2013-15 in the districts of North 24 Pgs, Nadia and Hooghly of West Bengal. Field demonstrations were conducted to show the advantages of CRIJAF Nail weeder. It was operated during 7-30 days after sowing (DAS) of jute seed depending upon the field condition. Attitude towards its application for eradication of weeds in jute field and the socio-psychological profiles (age, education, socio economic status, farming experience, sources of information utilization) influencing it were documented.

RESULTS

Majority of the farmers had positive attitude towards use of CRIJAF Nail Weeder. Their age, education, socio-economic status, farming experience and sources of information utilization were positively associated with it. As per their views, it was quiet effective in eradication of composite type of weeds in jute field and other line sown crops like upland rice, moong, French bean etc. It helped in mulching. They liked it, because it saved the requirement of manual labour by 60-70%. It also saved upto Rs. 10,000-18,000/ha. Thus, the new technology augmented their income and livelihood.

CONCLUSION

Now a days, increasing cost of cultivation is a major concern for farming community. In general, adoption of technology able to minimize the cost of cultivation and lead to better utilization of local resources of farming community.

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New herbicide application techniques for the management of aquatic weeds in Australasia

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The main aquatic weeds posing challenges in Australia and New Zealand include floating, submerged, emergent and shoreline species. These are: (a) Floating- Salvinia (*Salvinia molesta* D.S. Mitchell); Water Hyacinth [*Eichhornia crassipes* (Mart.)Solms]; Azolla (*Azolla pinnata* R. Brown) and Water Lettuce (*Pistia stratiotes* L.); (b) Submerged species - Cabomba (*Cabomba caroliniana* Gray); Egeria (*Egeria densa* Planch); Lagarosiphon [*Lagarosiphon major* (Ridley) Moss]; several Pondweeds (*Potamogeton*L. spp.) and Hornwort (*Ceratophyllumdemersum* L.); and (c) Emergent and shoreline species Alligatorweed [*Alternanthera philoxeroides* (Mart.) Griesb.]; Milfoil [*Myriophyllum aquaticum* (Vell.) Verdc.]; Mexican Water Lily (*Nymphaea Mexicana* Zucc.); Primrose Willows [*Ludwigia peruviana* (L.) Hara; and *Ludwigia longifolia* (DC.) Hara]; Senegal Tea [*Gymnocoroniss pilanthoides* (D. Don) DC.] and Hygrophila (*Hygrophila costata* Sinning). Collectively, these have significant 'triple bottom line' impacts, which are environmental (reducing biodiversity), economic (annual, recurrent costs of control), and social (reduced aesthetic values and recreational opportunities associated with water bodies and waterways).

The submerged aquatic weeds prefer clear water, where they form dense stands, out-competing native vegetation and causing problems for water users. The problem in controlling these plants relates to their mode of spread; the smallest viable vegetative fragment can re-establish a population. Left uncontained, these aquatic weeds often fully colonize all available habitats, within a short period of time. In most cases, aquatic weed eradication is not an option, but they can be judiciously and cost-effectively managed using aquatic herbicides.

While the aquatic herbicides Diquat and Endothal have been around for a long time, new application techniques have been developed in New Zealand and Australia, which significantly improve their efficacy and cost-effectiveness. Results from New Zealand and Australian trials using these new techniques are presented, along with a description of the situations where they can be utilised.

The improvement in Diquat efficacy has enabled the eradication of *Ceratophyllum* in several New Zealand streams. In several test trials conducted in NSW, Australia, similar success has been achieved in the management of *Egeria* and *Ceratophyllum*. This involved the use of guar gum, and formulating a Diquat gel (Aquagel[â]), which was then applied to the water.

The herbicide Endothal (Aquathol K[â]) is also available for use in New Zealand waterways, and if applied correctly, it has shown the potential to eradicate a range of submerged aquatic weeds. There is further scope for significant expansion of using Aquagel[â] and Aquathol K[â] to control submerged aquatic weeds in Australia and New Zealand without undue environmental impacts (Hofstra*et al*. 2001, Wells and Clayton 2005).

Most non-chemical methods have been of limited value in controlling or eradicating aquatic weeds in New Zealand. Thus, the herbicide compounds Diquat and Endothal are now widely used New Zealand. In Australia, only Diquat is registered for aquatic applications, which is a limitation. Each of these compounds has its advantages and disadvantages, and their effectiveness against different aquatic weed species varies considerably.

CONCLUSION

In New Zealand and Australia, we have developed application techniques to improve the efficacy of Endothal and Diquat, taking account of the target weed species, water conditions, time of year and environmental effects. Good control and even eradication of some weed species can be achieved, if these techniques are correctly employed. When properly used, the environmental impacts are benign, and economic benefits quite impressive. There is scope for using these techniques elsewhere in the Asia-Pacific region to control aquatic weeds, as has been adequately demonstrated in Australian and New Zealand waterways.

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Herbicide resistant crops: A better option for weed management in India

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Crops made resistant to herbicides by biotechnology are being widely adopted in many countries for commercial cultivation. But in India, the technology of herbicide tolerant crops is in initial stage of field evaluation. Hence, field trials have been carried out to evaluate the agronomic advantages of herbicide tolerant transgenic cotton and maize.

METHODOLOGY

Herbicide tolerant stacked traits of maize and cotton were evaluated under Bio-safety Research Level (BRL I) as confined field trials for its agronomic efficiency on weed control and enhanced crop productivity at TNAU, Coimbatore for three years(2010-2013). In both crops, potassium salt of glyphosate was sprayed at different doses (900, 1350, 1800, 2700, 3600 and 5400 g/ha twice at 25 and 60 DA Sin cotton and 900,1800 and 3600 g/ha at 25 DAS in maize). Evaluation was made on weed control efficiency, phytotoxicity on crops, yield and economics and carryover effects on the succeeding crops.

RESULTS

Application of glyphosate at 2700 g/ha recorded lower weed density, dry weight and higher WCE (Table1.) in cotton. POE glyphosate at 900, 1800 and 3600 g/ha registered lower weed density, dry weight and higher WCE in transgenic Hishell and 900 M Gold (Table2.) and in 30V92 and 30B11 corn hybrids (Table3.). Grichar *et al.* (2004) had found that single application of glyphosate as early or late post emergence effectively controlled the broad spectrum of weeds.

Table 1. Effect of Glyphosate on WCE and seed cotton yield in transgenic cotton

Treatment	Winter,2009-10		Winter,2010-11	
	WCE (%)	Yield (kg/ha)	WCE (%)	Yield (kg/ha)
Gly. 900 g/ha	93.36	2607	91.27	2470
Gly. 1350 g/ha	95.02	2841	92.44	2575
Gly. 1800 g/ha	97.97	2984	95.12	2846
Gly. 2700 g/ha	98.37	3195	96.29	3092
HW 15& 30 DAS	95.48	2504	74.91	2323

Table 2. Effect of Glyphosate and Atrazine on WCE and grain yield in transgenic corn

Treatment	WCE (%)	Grain yield (t/ha)
T. Hishell POE glyphosate 900g/ha	93.83	9.91
T. Hishell POE glyphosate 1800 g/ha	96.69	10.34
T. 900 M Gold POE glyphosate 900 g/ha	94.42	9.95
T. 900 M Gold POE glyphosate 1800 g/ha	95.41	10.46
Hishell PE atrazine 0.5 kg/ha + HW + IC	91.54	9.23
900 M Gold PE atrazine 0.5 kg/ha + HW + IC	88.38	8.77

Post emergence application of glyphosate in transgenic maize hybrids did not affect the germination per cent, vigour and yield of succeeding green gram in the transgenic maize trials and sunflower, soybean and pearl millet in cotton trials. Phytotoxicity symptoms were not observed in cotton with glyphosate at lower doses, *viz.* 900, 1350, 1800 and 2700 g/ha, whereas higher doses, *viz*. 3600 and 5400 g/ha showed phytotoxicity symptoms at early stages.

Glyphosate applied at 900, 1350, 1800 and 2700 g/ha recorded more number of bacteria, fungi and actinomycetes in soil compared to atrazine treatment. Results corroborate the observations of Weaver *et al*. (2007) who had reported that glyphosate had only small and transient effects on the soil microbial community. Higher grain yield was recorded with POE application of glyphosate at 900, 1800 and 3600 g/ha in Hishell and 900 M Gold transgenic hybrids (Table2) and higher net return and benefit cost ratio were recorded in glyphosate at 1800 g/ha in transgenic 900 M Gold in all the four seasons. Post emergence application of glyphosate at 900 and 1800 g/ha registered higher grain yield in transgenic 30V92 and 30B11 corn hybrids (Table 3).

Table 3. Effect of Glyphosate and Atrazine on WCE and grain yield in transgenic corn hybrids

Treatment	WCE (%)	Grain yield (t/ha)
30V92 HR Glyphosate 900 g a.e/ha	98.56	11.10
30V92HR Glyphosate 1800 g a.e/ha	99.53	12.21
30B11HR Glyphosate 900 g a.e/ha	97.72	10.97
30B11HR Glyphosate 1800 g a.e/ha	98.97	11.98
30V92 PE atrazine 0.5 kg/ha + HW+ IC	72.57	10.23
30B11 PE atrazine 0.5 kg/ha + HW+ IC	70.33	9.76

CONCLUSION

In transgenic glyphosate tolerant maize and cotton, post emergence weed management with glyphosate proved to be the better management option for the control of weeds.

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Management of weedy rice by DCA using novel wick applicator

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India has the earliest history of rice cultivation and introgression between perennial wild rice and cultivated rice has given rise to highly variable population of weedy/wild rice forms, including annuals and perennials. Taxonomically, Indian weedy rice has been reported to be *Oryza sativa* f. *spontanea*, belonging to indica group (Vaughan, 1994). Management of weedy rice infestation is complex mainly because of its morphological similarities to cultivated rice, lack of herbicides for selective control of weedy rice in cropped fields, seed shattering and variable seed dormancy leading to staggered germination (Chauhan, 2013). Efficient replenishment to the soil seed bank also adds to the severity of infestation, invasion and spread. As the recommendations of chemical weed control in rice were not effective for selective control of weedy rice, the present research programme was undertaken during 2012-14 to design a novel prototype of wick applicator for direct contact application of herbicides, to prevent the build-up of soil seed bank in severely weedy rice infested areas.

METHODOLOGY

Direct contact application (DCA) of non-selective broad-spectrum post - emergence herbicides is a management strategy for the control of tall growing weeds than rouging. The new prototype of the hand held herbicide wiper device developed has a five litre herbicide containing tank which can be hung on the shoulder of the operator. A sprayer pump is attached to the herbicide tank to develop pressure. The pressurized herbicide from the tank flows through a hose, placed on a 'U' shaped frame fitted with a handle. A nozzle present at the proximal end of the hose is used to dispense the herbicide. Chances for dripping of the herbicide can be avoided by an easy to operate control valve with button switch or tilting the device to spread the chemical on to the cloth, fastened on the herbicide carrying 'U' shaped frame of the device. The 'U' shaped hose mounting frame is connected to the front end cap of handle which in turn was connected to the rear end cap. The hose dummy is present at the distal end of the hose to seal the end of the hose. The 'U' shaped hose has eight pores, four pores on each parallel limb. The pores are covered with a cloth towel which gets saturated by the herbicide coming out from the pores. Herbicide can be smeared on both the sides of the panicle along the entire length by the horizontal swinging movement of the wick applicator. The efficiency of various broad spectrum non selective herbicides in selective drying of weedy rice panicles by DCA was experimented using the novel wick applicator.

RESULTS

Utilizing the earliness in flowering of weedy rice plants compared to rice plants (10-15 days) and consequent difference in height of weedy rice panicles and rice plant at 60-65 DAS, it was possible to dry 75-85% earheads of weedy rice by direct contact application of non-selective broad-spectrum herbicides.

Glufosinate ammonium at 15% concentration had the highest percent of weedy rice control followed by glyphosate and paraquat dichloride at 15% and glufosinate ammonium 15 at 10% concentration. Ferrero *et al.* (1999) have observed 90% reduction in germination of dried seeds collected after sweeping weedy rice panicles with wick applicator using glyphosate (10-15%) at 65 DAS in infested cropped fields. The dried ear heads were collected for checking the viability using tetrazolium test and it was found that majority of the spikelets were either in the dough stage or sterile. The ear heads which dried on application of the herbicide subsequently fell off from the plant within 10-15 days. While using glyphosate, it was noticed that the entire weedy rice plant dried by the action of the herbicide. This mode of control is highly energy efficient, less labor intensive, and eco-friendly compared to hand weeding, cutting of weedy rice ear heads or application of large quantity of herbicides using sprayers. The chances for weedy rice seed rain to soil can also be very effectively prevented by DCA. In Kerala Agricultural University, a novel wick applicator has been developed and found effective on field testing.

CONCLUSION

The novel hand held wiper device developed for DCA of non-selective broad-spectrum herbicides, glufosinate ammonium at 15%, paraquat dichloride at 15% or glyphosate at 10-15% concentration was effective as a weedy rice management. The device was filed for Indian Patent at Patent Office, Chennai (Application No. 1763/CHE/2014 dated 01.04.2014).

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Residue of oil palm frond mulch as slow-release carriers for herbicide

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Organic mulch by using crop residues is increasingly popular because it has a number of advantages in cropping system and provides an excellent weed control. In the present study, a similar approach was investigated using residues of oil palm frond. This crop residue was selected due to the rapid development in the Malaysian oil palm industry, thereby resulting in increased of fibrous wastes derived from harvesting of the crops, management practices and replanting operations. The main objective of this study was to evaluate the efficacy of oil palm frond residue combined with imazethapyr as mulch for long term weed control.

METHODOLOGY

After many laboratory and glasshouse experiments (Dilipkumar *et al.* 2015), a field study was conducted to evaluate the phytotoxic activity of oil palm frond mulch treated with imazethapyr at reduced rate on weeds in the coconut farm. The experiment was conducted in the 5 year-old coconut plantation at MARDI Hilir Perak, Malaysia. The soil texture was silt loam with pH 4.91 and 0.4% of organic carbon content. The herbicide treated oil palm frond mulch was applied along with other treatments under the canopy area of young coconut trees (radius 1.8m). The experiment was arranged in a completely randomized block design with four replications. Four months after treatments, weed density and weed dry weight were determined by using quadrat system ($1m^2$). All the data were checked for homogeneity of variance test before being subjected to ANOVA.

RESULTS

Six major weed species, namely *Asystasia gangetica*, *Echinochloa colona*, *Panicum* sp., *Mikania micrantha* and *Phyllanthus amarus* were chosen to evaluate the effectiveness of different treatments. All the treatments evaluated have no significant effects on the density of each weed species (Table 1). However, plots receiving treatment of hand weeding followed by 24 g/ha imazethapyr-treated oil palm frond mulch at 3.4 t/ha had lower total weed density as compared to those of hand weeding alone and hand weeding followed by application of oil palm frond mulch at 4 t/ha. Furthermore, imazethapyr-treated oil palm frond mulch - provided excellent weed control where it reduced total weed dry weight by 93% by 4th month as compared to control plot (Table 1).

Table 1. Weed density (no/m^2) and weed dry weight (g/m^2) influenced by different weed control treatments (after 120 days)

Treatment	*Asystasia gangetica*	*Echinochloa colona*	*Panicum* sp.	*Mikania micrantha*	*Phyllanthus amarus*	Total
Control (hand weeding *fb* weedy check)	12.8 a (62.0 c)*	20.8 a (45.8 b)	18.3 a (142.8 c)	7.0 a (18.2 bc)	12.4 a (5.9 ab)	14.3 b (51.7 bc)
Hand weeding *fb* OPM at 4 t/ha	19 a (36.6 bc)	29.7 a (65.7 c)	5.8 a (40.2 b)	15 a (15.9 bc)	9.3 a (5.8 ab)	16.2 b (35.3 bc)
Hand weeding *fb* OPM at 3.4 t/ha + imazethapyr at 24 g/ha	5.5 a (3.1 a)	7.3 a (6.4 a)	3.6 a (5.6 a)	2.8 a (0.2 a)	4.4 a (0.5 a)	4.9 a (3.4 a)
**Slashing *fb* glyphosate at 1.83 kg/ha	12.2 a (38.7 bc)	8.0 a (42.2 b)	6.3 a (53.1 b)	7.2 a (11.9 bc)	12.3 a (12.6 b)	8.9 ab (33.7 bc)
Glyphosate at 1.83 kg/ha	7.0 a (25.8 b)	18.8 a (53.3 b)	15.8 a (141.6 c)	8.0 a (9.9 bc)	14.2 a (15.8 b)	12.9 ab (49.9 bc)
Slashing	18.2 a (64.4 c)	8.8 a (48.4 b)	6.5 a (34.2 b)	3.8 a (4.6 ab)	6.4 a (17.7 b)	9.9 ab (35.5 bc)

*Values in parentheses represent weed dry weight and without parentheses represent weed density.; **T4 is a common farmer's practice for weed control in coconut plantation in Malaysia. Glyphosate was applied when the weed plant height is up to 5-10 cm after slashing.

CONCLUSION

Use of imazethapyr at 24 g/ha along with oil palm frond residues at 3.4 t/ha acted synergistically and gave significant reduction of weed emergence and growth up to 4 months under the canopy area of young coconut trees. It also reduced the application rate of imazethapyr up to 90%, thus promoting cheap and less polluted approach for sustainable weed management. The output of this project will lead to the utilization of oil palm frond residue for designing mulch product as slow release carriers for herbicide for long term weed control. This invention has been filed for patent (Malaysia Patent No: PI 2014703195, Dilipkumar *et al.* 2014).

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Newfangled strategies to exhaust seed bank of world's worst weed, *Cyperus rotundus*

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Cyperus rotundus is ranked as one of world's worst weed (Holm *et al.* 1977). It is a difficult weed to eradicate due to extensive underground tubers. Jangaard *et al.* (1971) noted that the presence of apical dominance will keep the daughter tubers dormant. . Hence it is decided to manage *C. rotundus* with a new approach, to break dormancy and to exhaust the seed bank. With this background, the research work was programmed.

METHODOLOGY

Zinc oxide (ZnO) and Iron oxide (Fe_2O_3) nanoparticles were chosen for degrading phenolic compounds present in the tubers of *Cyperus rotundus*. The tubers were collected from various fields for the analysis. They were sorted based on diameter and tubers of uniform diameter were chosen for phenol degradation and dormancy breaking studies. Tubers were treated with synthesized ZnO and Fe_2O_3 nano particles at the concentration of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 g/kg of tubers for 24 hours. Phenol estimation was done with this sample using the folin ciocalteau procedure. Germination percentage was calculated for the treated tubers to ensure the dormancy breaking ability of the nano particles.

RESULTS

Significant variation on phenol degradation was observed with different concentration of ZnO and Fe2O3 nano particles**.** Fe_2O_3 nano particles at 3.0 g/kg tuber - recorded higher percentage of phenol degradation (89.1%) over control, which was on par with 2.5 g/kg tuber (87.2% over control). Higher percentage of phenol degradation was observed with ZnO nanoparticles at 2.0 g/kg tuber (56.2%), which was on par with 1.5 g/kg tuber).

Table 1. Effect of nanoparticles on phenol degradation of *Cyperus rotundus*

S.no	Concentration of nps (g/kg of tuber)	Phenol concentration (mg/ g of tuber)	
		Fe_2O_3 nps	ZnO nps
1	Control	21.78	9.60
2	0.5	10.67	5.90
3	1.0	6.39	5.10
4	1.5	5.70	4.80
5	2.0	4.41	4.20
6	2.5	2.79	5.30
7	3.0	2.38	5.18
LSD(P=0.05)		0.92	0.65

CONCLUSION

Fe_2O_3 at 2.5 to 3.0 g/kg of tubers and ZnO nanoparticles at 1.5 to 2.0g/kg of tubers were effective in degrading the inhibitor of *Cyperus rotundus*, which might help in sprouting of tubers. .

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Technical Session 7

Weed management in horticulture and plantation crops and crops other than rice

The combination effect of MSMA and diuron in controlling glyphosate resistant *Eleusine indica* in oil palm plantation

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In every production system of crops, the recognized vital component is weed management. This is because the presence of weeds affects the yield and growth of crops due to competition in terms of basic growth requirement. Typically, weeds compete with crops for water, light and soil nutrients (Zimdahl, 2007). Goosegrass (*Eleusine indica*) is one of the weeds that have problems associated with herbicide resistance. *E. indica* is normally controlled by herbicides such as glyphosate. The intensive use of herbicides has resulted in the weed developing herbicide resistance (Heap and Lebaron, 2001). In Malaysia, the first case of glyphosate-resistant *E. indica* was reported in a four-year-old orchard in Teluk Intan, Perak in 1998 after glyphosate failed to control of *E. indica* adequately. The level of resistance in the resistant biotype in Teluk Intan was found to be 8 to 12 times higher than the susceptible biotype (Lim and Ngim, 2000). Therefore, the objective of this study was to test the efficacy of a herbicide mixture of MSMA 39.5%w/w and Diuron 7.8%w/w in SC formulation, and its tank-mix with Paraquat dichloride 13%w/w or Glufosinate ammonium 13.5%w/w, for controlling the resistant biotype *E. indica* in a nursery trial.

It was observed that resistance of *E. indica* to glyphosate was significant as only 10% of the *E. indica* treated with glyphosate was killed during the experiment. It was noted that treatments T1 to T4 recorded significantly higher percentage kill of goose grass ~~at~~ (more than 95%) compared to T5 and T6 at one week after treatment. T3 and T4 recorded 100% *E. indica* kill at four weeks after treatment (Table 1).

Table 1. The percentage mortality of *E. indica* treated with various treatments of herbicides

Treat.	Active ingredients	Rate	Percentage of *E. indica* killed (%)			
			Week 1	Week 2	Week 3	Week 4
T1	MSMA 39.5%w/w + Diuron 7.8%w/w	5L/Ha	95a	99a	99a	99a
T2	(MSMA 39.5%w/w + diuron 7.8%w/w) + Paraquat dichloride 13%w/w	3L/Ha + 3L/Ha	98a	98a	98a	98a
T3	(MSMA 39.5%w/w + diuron 7.8%w/w) + Paraquat dichloride 13%w/w	3.5L/Ha + 3L/Ha.	98a	99a	99a	100a
T4	Glufosinate ammonium 13.5%w/w	3.3L/Ha	95a	99a	99a	100a
T5	Paraquat dichloride 13%w/w	6L/Ha	80b	80b	80b	80b
T6	Glyphosate isopropyl ammonium 41%w/w	3L/Ha	10c	10c	10c	10c
T7	Control (water only)		0d	0d	0d	0d

*Different letters denote a significance ($p<0.05$) between treatments; data analyzed by Tukey HSD

CONCLUSION

In the experiment, resistance of *E. indica* to glyphosate was observed to be significant as only 10% of the *E. indica* treated with glyphosate was killed. This study shows that glufosinate ammonium 13.5%w/w or the combination of (MSMA 39.5%w/w + Diuron 7.8%w/w) + Paraquat dichloride 13%w/w (3.5L/Ha + 3L/Ha) can effectively control *E. indica*.

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Influence of weed management practices on weed dynamics and productivity of fennel

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Fennel (*Foeniculum vulgare* Mill.) generally takes longer time for germination and also has slow initial growth which often leads to heavy infestation of weeds. If not controlled timely, these weeds adversely affect the growth and cause huge losses in yields. The losses in yield could be as high as 91.4 % as reported by Mali and Suwalka (1987). Therefore, weed management is one of the most crucial factors in realising optimum yields. Manual weeding is the common practice in fennel to keep the weeds under check. However, timely availability of labourers and higher costs involved are the major constraints in effective weed management in fennel. Suitable alternatives involving herbicide use is the need of the hour for effective and efficient control of weeds in fennel to ensure optimum yields and reduce the dependence on manual labour. Studies have shown that herbicide application effectively controls the weeds and can increase the seed yield of fennel by 43.2 to 86.9 % (Voevodin and Borisenko, 1981).

METHODOLOGY

A field experiment on effective and efficient weed control in fennel was conducted at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during *Rabi* season of 2011-12, 2012-13 and 2013-14. The experiment comprising fourteen treatments including unweeded check (control treatment) was laid out in randomized complete block design (RCBD) with three replications. Pendimethalin (0.50, 0.75, 1.0 kg/ha and 0.50 kg/ha *fb* one hand weeding at 40 days after sowing), Trifluralin (0.50, 0.75, 1.0 kg/ha and 0.50 kg/ha *fb* one HW at 40 DAS) and Oxyfluorfen (150, 175, 200g/ha and 150 g/ha *fb* one HW at 40 DAS) were tested against two hand weeding (20 and 40 DAS). The crop was sown in the second fortnight of October and harvested in May. Trifluralin was applied as pre-plant incorporation whereas pendimethalin and oxyfluorfen were applied as pre-emergence on the next day after sowing by mixing with 375 litres of water per ha, using knapsack sprayer fitted with flat fan nozzle. The data on weeds, yield attributes and crop yield were recorded at time of harvesting. The weed data were subjected to square root transformation before analysis.

RESULTS

The weed flora mainly consisted of *Rumex dentatus, Rumex spinosus, Medicago denticulatae–, Chenopodium album, Anagallis arvensis, Malva parviflora, Phalaris minor, Avena ludoviciana,* etc. All the weed control treatments significantly reduced the weed infestation (weed dry matter) and increased the yield of fennel when compared with the control (unweeded check). Among different treatments, pre emergence application of pendimethalin 1.0 kg/ha was found most effective in reducing weed dry matter production and significantly better than trifluralin and oxyfluorfen treatments in terms of umbels/plant and seed yield of fennel. The seed yield of fennel with application of pendimethalin 1.0 kg/ha was 1117, 1435 and 1353 kg/ha during 2010-11, 2012-13 and 2013-14, respectively. Lower dose of pendimethalin i.e. 0.5 kg/ha followed by one hand weeding at 40 day after sowing (DAS) or two hand weedings at 20 and 40 DAS were also found effective and statistically at par with that of pendimethalin 1.0 kg/ha. Meena and Mehta (2009) have also reported similar findings. Though the application of oxyfluorfen (200g/ha or 150g/ha fb one HW at 40 DAS) was equally effective as pendimethalin (1.0 kg/ha or 0.5 kg/ha fb one hand weeding at 40 DAS) in reducing the weed infestation, it could not increase the yield as it caused phytotoxicity at the initial growth stages of fennel.

Table 1. Effect of different weed control treatments on growth, yield of Fennel and weed dry matter

Treatment	Umbels (No. /plant)			Seed yield (kg/ha)			Weed dry matter at harvest(g/m^2)		
	2011-12	2012-13	2013-14	2011-12	2012-13	2013-14	2011-12	2012-13	2013-14
Pendimethalin 0.5 kg/ha	12.67	15.60	13.17	716	817	793	8.25 (67.40)	9.44 (88.53)	8.94 (79.40)
Pendimethalin 0.75 kg/ha	15.00	20.70	16.93	864	1104	1033	6.33 (40.80)	7.18 (51.07)	6.79 (45.13)
Pendimethalin 1.0 kg/ha	19.00	26.10	21.57	1117	1435	1353	4.58 (20.37)	5.00 (24.10)	4.55 (19.80)
Pendimethalin 0.5 kg/ha *fb* HW (40 DAS)	18.33	25.80	21.13	1089	1424	1330	4.13 (17.40)	5.47 (29.83)	4.59 (21.27)
Trifluralin 0.5 kg/ha	12.33	14.70	12.53	688	758	743	8.70 (74.80)	10.74 (114.6)	9.91 (97.33)
Trifluralin0.75 kg/ha	14.00	16.20	14.10	795	843	853	7.98 (64.63)	9.52 (89.93)	8.92 (78.70)
Trifluralin 1.0 kg/ha	14.67	17.99	15.37	833	967	940	7.03 (49.27)	8.28 (67.67)	7.70 (58.57)
Trifluralin 0.5 kg/ha *fb* HW (40 DAS)	15.00	19.75	16.87	833	1057	1047	6.06 (36.07)	7.77 (59.87)	7.09 (49.57)
Oxyfluorfen 150 g/ha	12.00	15.30	12.67	710	809	787	7.57 (56.27)	8.57 (72.90)	8.12 (65.10)
Oxyfluorfen 175 g/ha	14.67	19.50	16.13	870	1064	1013	6.08 (38.17)	7.40 (54.10)	7.39 (53.83)
Oxyfluorfen 200 g/ha	15.33	20.10	16.77	897	1098	1047	4.15 (16.67)	4.77 (22.90)	4.21 (16.90)
Oxyfluorfen 150 g/ha *fb* HW (40 DAS)	17.33	20.70	18.00	993	1120	1113	4.09 (16.17)	4.65 (21.63)	4.07 (16.50)
Two HW (20 and 40 DAS)	19.33	24.90	21.47	1122	1368	1350	3.90 (14.27)	5.19 (26.37)	4.07 (15.73)
Control	9.33	10.80	9.13	433	467	457	15.29(233.3)	17.37 (302.3)	16.81 (282.57)
LSD(P=0.05)	3.30	4.57	3.49	198	244	231	1.78	1.60	1.25

*Values in parentheses are original. Data transformed to square root transformation

CONCLUSION

Pre-emergence application of pendimethalin 1.0 kg/ha or integration of lower dose of pendimethalin i.e. 0.50 kg/ha *fb* one hand weeding (40 DAS) was found most effective in reducing the weed infestation and enhancing the seed yield of fennel.

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Herbicides and polythene mulching effects on yield of irrigated cassava

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Cassava (*Manihot esculenta* Crantz), a tuberous root crop is rich in carbohydrate. It is grown for food, feed and raw material for industries. In India, it is cultivated in Tamil Nadu, Kerala, Andhra Pradesh, Maharashtra, Gujarat, Odisha and North-Eastern states in a total area of 0.24 million ha with an annual production of 9.94 million tones of roots (NHB, 2013). Weed infestation is one of the major constraints for cassava cultivation due to its slow initial growth and wide plant spacing. Under irrigated conditions farmers do up to five hand weedings for cassava and weeding consumes about 50% of total labour inputs (Ravindran *et al*. 2010). Herbicides and polythene mulching are alternatives for hand weeding. However, their impact on yield and quality of root is vital. Hence, the present investigation was undertaken.

METHODOLOGY

A field experiment was carried out for three consecutive years (2010-11 to 2012-13) at the ICAR-Central Tuber Crops Research Institute, Regional Centre, Dumuduma, Bhubaneswar under irrigated conditions on alfisols (Typic Rhedustalfs). The experiment was laid out in a randomized block design (RBD) with three replications. The treatment details are presented in Table 1. The pre emergence herbicide oxyfluorfen 0.06 kg/ha was applied, one day after planting (DAP) cassava, on the ground directly leaving the setts. Post emergence herbicide glyphosate 2.0 kg/ha was applied directly on weeds at 3 M A P. Black polythene sheet (100 micron) was spread covering the ridge and furrows and the ends were secured by covering with soils. The variety H-226 was planted at 75 cm x 75 cm spacing. The crop was irrigated through drips as and when required. Irrigation was withheld 15 days before harvest. Farmyard manure (FYM) 12.5 t/ha and $N-P_2O_5-K_2O$ at 100-75-100 kg/ha was applied. FYM was incorporated in the last plough. Full dose of phosphorus and half doses of nitrogen and potassium were applied as basal at the time of planting and the remaining half doses of nitrogen and potassium were applied three months after planting (MAP) through drip irrigation. The crop was harvested at 10 MAP. Data on weed dry matter, yield and economics were recorded.

RESULTS

Grasses and broad-leaved weed species emerged in flushes as soon as cassava was planted due to high rainfall and protective irrigation. One sedge, four grass and seven broad-leaved weed species were observed in the cassava fields. Among weed species, *Celosia argentia* L., *Digitaria sanguinalis* L. and *Cleome viscosa* L. grew robustly and quickly, and dominated the weed flora. Black polythene mulching and four hand weedings (at 1, 2, 3 and 4 MAP) resulted in significantly lower weed dry matter, higher weed control efficiency and higher root and shoot yield compared to other treatments (Table 1). The root yield was lower by 9.6% with pre emergence application of oxyfluorfen + two hand weedings (at 2 and 3 MAP) and 10.1% with two hand weedings (at 1 and 2 MAP) + post emergence application of glyphosate (at 3 MAP) compared to four hand weedings (at 1, 2, 3 and 4 MAP).

Table 1. Effect of weed management practices on weed dry matter, yield and economics of irrigated cassava (3 years pooled data)

Treatment	Weed dry matter (g/m^2)	Weed control efficiency (%)	Fresh root yield (t/ha)	Shoot yield (t/ha)	Root starch content (%)	Cost of cultivation (`/ha)	Gross return (`/ha)	Net return (`/ha)	B:C ratio
Weedy check	14.6 (212.4)	-	12.5	14.2	24.0	27750	50000	22250	1.80
Two hand weeding (at 1 and 2 MAP)	8.1 (63.9)	69.9	27.0	29.6	25.5	51100	108000	56900	2.11
Four hand weeding (at 1, 2, 3 and 4 MAP)	4.4 (18.6)	90.8	36.5	34.6	27.3	69950	146000	76050	2.09
Oxyfluorfen @ 0.06 kg/ha (pre emergence application at 1 DAP)	9.2 (83.0)	60.9	24.7	27.1	26.3	34200	98800	64600	2.89
Oxyfluorfen @ 0.06 kg/ha (pre emergence application at 1 DAP) + one hand weeding (at 3 MAP)	6.7 (43.3)	79.6	30.4	32.0	26.7	46050	121600	75550	2.64
Oxyfluorfen @ 0.06 kg/ha (pre emergence application at 1 DAP) + two hand weeding (at 2 and 3 MAP)	6.3 (38.2)	82.0	33.0	33.8	27.0	56250	132000	75750	2.35
Glyphosate @ 2.0 kg/ha (post emergence application at 1 MAP)	7.6 (57.1)	73.1	27.7	30.1	25.5	36750	110800	74050	3.01
One hand weeding (at 1 MAP) + glyphosate @ 2.0 kg/ha (post emergence application at 2 MAP)	5.9 (33.3)	84.3	31.7	33.0	24.9	48550	126800	78250	2.61
Two hand weeding (at 1 and 2 MAP) + glyphosate @ 2.0 kg/ha (post emergence application at 3 MAP)	5.4 (27.8)	86.9	32.8	33.5	24.2	58400	131200	72800	2.25
Black polythene mulching	2.0 (3.2)	98.5	34.1	34.0	26.1	62450	136400	73950	2.18
LSD (P=0.05)	0.5	-	2.7	2.8	1.6	3246	7482	5143	0.12

*Figures in parenthesis indicate original values. Data transformed to square root transformation (x + 1); **sale price of tuber Rs 4/kg.

The lowest starch content in roots was observed in weedy check and post emergence application of glyphosate (at 2 and 3 MAP) along with hand weeding (Table 1). This might be due to higher weed density (weed dry weight) in the former case and rhizosphere glyphosate (exuded by weed roots) (give supporting data or reference) absorbed by the cassava roots interfering in starch accumulation in the latter case. Inclusion of herbicide reduced the cost of cultivation. Maximum gross return was obtained with four hand weedings (at 1, 2, 3 and 4 MAP) and black polythene mulching due to higher root yields. But, net returns and B: C ratio were lower because of higher human labour requirement and their wages in the former case and higher cost of black polythene in the latter case. Inclusion of herbicide resulted in higher net returns and B: C ratio because of reduced cost of cultivation (Table 1).

CONCLUSION

Black polythene mulching is considered a good weed management option, where weeds are a serious problem and drip irrigation facilities are available. Pre emergence application of oxyfluorfen (0.06 kg/ha) (1 DAP) + two hand weedings (at 2 and 3 MAP) or two hand weedings (at 1 and 2 MAP) + post emergence application of glyphosate (2.0 kg/ha) (at 3 MAP) can be a weed management option, where labourers are scarce.

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Effect of tillage and weed control methods on productivity and profitability of maize

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Maize is one of the main foods for millions of people due to compatibility with different climatic conditions. Also, its area harvest has the third place around the world (Liebman *et al.* 2001). Maize is most sensitive to weeds competition especially during early stage of crop growth. It grows slowly during first 3 to 4 weeks. The highest damage is caused by weeds, pests and diseases. This damage is estimated between 10 to 15% of total production in developed countries in temperate zones, so it is more in developing countries in tropics zone. Therefore, the farmers sometimes spend more than half struggle to control weeds (Rashed et al., 2001). Weeds compete with crop in different ways, and decrease quality and quantity of agricultural products. Results of some studies showed that weeds are able to use nutrition of soil more than crops (Yadavi *et al.* 2008; Rashid *et al.* 2008). The weeds can grow in the beginning season due to the use of feature that reduces potency of competition plants by creating food shortages. Many research results showed that plowing increase weed population. However, other studies indicated that weeds population is higher in none tillage and reduced tillage methods (Smith, 2006). It is reported that a deep plowing reduced weeds due to transfer seeds through deep soil, and shallow plowing and reduced tillage increased the density of weed seeds due to transport through the soil surface. Tillage methods have significant effect on grain yield, biological yield, grain number per corn and leaf index (Abdollahi *et al.* 2011). Combination of different methods of weed control appears necessary due to importance of weed management in corn crop and the researchers recommended the use of non-chemical methods in agriculture, also, in order to increase more and healthier produce. The aim of this study was to determine the effects of weed control methods under different tillage sequences adopted during kharif and winter seasons on weed population density and maize yield.

METHODOLOGY

A field experiment was conducted at agronomical research farm of Birsa Agricultural University during rainy seasons of 2013 and 2014 to find out the effect of tillage and weed control methods on productivity and economics of maize production. The treatments comprised of five different tillage methods in main plots i.e. conventional tillage both in kharif and in winter seasons (CT-CT), conventional tillage in kharif and zero tillage in winter seasons (CT-ZT), zero tillage both in kharif and winter seasons (ZT-ZT),zero tillage in kharif and zero tillage in winter season along with crop residue (ZT-ZT+R) and zero tillage along with crop residue in kharif and winter seasons (ZT+R-ZT+R) and weed control methods in sub plots namely recommended herbicide i.e. atrazine 1.0 kg/ha (RH), integrated weed management containing intercropping by black gram + pre emergence application of pendimethalin 1.0 kg/ha + manual weeding at 30 days after sowing (IWM), and weedy check. The experimental soil was poor in nitrogen (167 kg/ha) and phosphorus (19 kg/ha)and medium in potash (187 kg/ha) and the pH was 6.2.

RESULTS

The field was infested with major weeds like *Cyperus rotundus, Stellaria media, Digitaria sanguinalis, Alternenthera sessils, Commelina nudifolia, Paspalam distichum, Ageratum conzoides* and *Celosia argensia.* Conventional method of tillage performed in Kharif and winter seasons recorded reduced density of grassy and sedges weeds in maize crop at 30 and 60 DAS. The total weed density recorded under ZT+R-ZT+R at 60 DAS being similar to CT-ZT, ZT-ZT, and ZT+R-ZT+R was significantly lower compared to CT-CT to the extent of 23.68 percent during 2014. The weed dry matter accumulation (Table 2) during 2014 was significantly reduced under ZT+R-ZT+R to the extent of 13.25 percent compared to mean of rest of the tillage combinations. Among weed control methods, integrated weed management significantly reduced density of grassy, broad leaf and sedges weeds as well as total to the tune of 65.3, 66.2, 72.5 and 68.1% respectively compared to weedy checks at 30 DAS during 2013 . While at 60 DAS, IWM reduced grassy and broad leaf and total weeds to the extent of 82.4, 67.7 and 75.3% respectively compared to weedy checks during 2013.

Table 1. Effect of tillage and weed control methods on weed density (no./m^2) and weed dry matter at 60 DAS of Maize during 2013 and 2014 Kharif

Treatment	2013 Total weed density	2013 Weed dry matter	Average grain yield (kg/ha)	Average B:C ratio
Tillage methods				
CT-CT	14.02 (14.02)	9.01(88.47)	2046.0	0.81
CT-ZT	15.24 (15.24)	9.76(104.21)	1957.5	0.79
ZT-ZT	15.64 (281)	10.04(115.90)	2268.0	1.77
ZT-ZT+R	15.82 (289)	10.17(119.81)	2542.0	2.05
ZT+R-ZT+R	18.04 (365)	11.54(148.46)	2618.5	2.235
LSD (P=0.05)	NS	NS		
Weed control				
R – H	12.57 (161)	8.07(66.07)	2518.0	2.105
IWM	11.55 (135)	7.41(55.18)	2853.5	1.46
WC	23.13 (546)	14.83(224.86)	1488.0	1.025
LSD (P=0.05)	5.57	4.88	-	-

Conventional or zero tillage methods performed prior to sowing of maize crop did not influence grain nor straw yield of maize during 2013. However, during 2014 ZT+R-ZT+R being similar to CT-ZT , CT-ZT, ZT-ZT+R recorded 86.82 percent higher grain (3133 kg/ha) and similar to CT-ZT. CT-CT method of tillage during 2013 and ZT+R-ZT+R similar to ZT-ZT and ZT-ZT+R during 2014 recorded significantly higher gross return (Rs. 48032 and 60342 respectively) owing to higher grain and straw yield compared to rest of the treatments. The higher net return (Rs. 45652) and B:C ratio (3.19) was recorded under ZT+R-ZT+R which was similar to ZT-ZT and ZT-ZT+R compared to CT-CT and CT-ZT method of tillage.

Integrated weed management performed in maize crop recorded 16.33; 80.94 and 16.26; 98.93 percent higher gross return (Rs.52429 and Rs. 59497) and 3.33; 107.09 and 5.37; 138.90 percent higher net return (Rs. 31515 and Rs. 38583) during 2013 and 2014 similar to application of recommended herbicide compared to application of recommended herbicide and weedy checks. However, application of recommended herbicides in maize recorded significantly higher B:C ratio (1.48)during 2013 while during 2014 (2.73) it was similar to integrated weed management.

CONCLUSION

Thus it can be concluded that for higher productivity and profitability maize can be grown under zero tillage along with soil cover with crop residue of previous wheat crop.

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Weed control efficiency of different herbicides and their effect on growth and yield of American cotton in Northern India

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Cotton is an important cash crop of India owing to its pivotal role in agriculture. It is sensitive to weed competition during initial growth stages due to slow growth and wider spacing as they compete for nutrients, water, light and thus reduce the cotton yield substantially (Bukun, 2004). With increasing availability of the new chemicals, their weed control efficiency needs to be evaluated. Generation of such information through field experimentation under site-specific conditions is therefore very crucial for guiding cotton growers.

METHODOLOGY

The experiment was conducted during *Kharif* 2014 at Punjab Agricultural University, Research Station, Faridkot which lies in Trans-Gangetic agro-climatic zone, representing the Indo-Gangetic alluvial plains (30 ^{0} 40'N & 74 ^{0} 44 'E) of Punjab. The experiment comprising of 10 weed management treatments (**T_1:** Pendimethalin 1.0 kg a.i/ha as pre- emergence + one hoeing , **T_2**: Trifluralin 1.2 kg a.i /ha PPI + one hoeing,**T_3**: Quizalofop-ethyl 50 g a.i/ha at 2-4 weed leaf stage+one hoeing,**T_4**: Pendimethalin 1.0kg a.i/ha as pre-emergence +quizalofop-ethyl 50g a.i/ha at 2-4 weed leaf stage + one hoeing,**T_5**: Pyrithiobac -sodium 62.5g a.i/ha at 2-4 weed leaf stage + one hoeing ,**T_6**: Pyrithiobac-sodium 62.5g a.i/ha + quizalofop-ethyl 50g a.i/ha at 2-4 weed leaf stage + one hoeing,**T_7**: Glyphosate 1.0 kg a.i/ha as directed spray at 45 DAS,**T_8**: Weed free check,**T_9**: Farmer's practice and **T_{10}**: Weedy check/control) was conducted in randomized block design having four replications. Hand hoeing in all the treatments was given at 60 DAS while, in Farmer's practice, one hand hoeing at 60 DAS followed tractor hoeing at 90 DAS and application of glyphosate @0.5kg a.i/ha was done as directed spray to emerged weeds during rainy season. Weed population and biomass was recorded from quadrat measuring 50 cm × 50 cm and expressed per square meter. Data on growth, yield and other parameters were recorded from five randomly selected plants in each treatment plot while seed cotton yield (SCY) was recorded from whole plot.

RESULTS

The data in the Table.1 revealed that Weed management practices differed significantly for seed cotton yield as well as for other characters such as plant height, bolls/plant, boll weight and sympods per plant. Highest SCY was recorded for

Table 1. Growth and yield parameters, weed indices and monetary parameters under different weed management treatments

Treatment	Bolls /plant	Seed cotton yield (kg/ha)	Initial weed dry matter (g/m^2) 50 DAS	Final weed dry matter (g/m^2)	WCE (%)	Net returns (Rs/ha)	B:C ratio
T_1	41.5	3208	32.0 (34.2)	174.2 (13.2)	48.8	91404	2.10
T_2	44.0	2922	40.0 (39.1)	172.0 (13.0)	49.4	81105	1.94
T_3	44.7	3063	30.6 (32.7)	167.9 (12.9)	50.6	85978	2.00
T_4	49.0	3400	43.6 (41.3)	133.2 (11.5)	60.8	97018	2.11
T_5	43.1	3206	42.6 (40.6)	216.5 (14.7)	36.3	90883	2.07
T_6	50.5	3522	41.3 (39.9)	98.6 (9.9)	71.0	100916	2.14
T_7	42.1	2915	48.6 (44.1)	214.2 (14.6)	37.0	81069	1.95
T_8	54.5	3552	40.0 (39.1)	32.8 (5.8)	90.3	98393	1.93
T_9	33.0	1918	41.3 (39.9)	340.1 (18.4)	-	46093	1.31
T_{10}	38.8	3038	40.6 (39.5)	253.5(15.9)	25.5	85461	2.02
LSD(P=0.05)	8.3	435	NS	1.4	-	15674	0.26

Data for weed dry matter has been subjected to square root transformation, respectively.Figures in parenthesis are means of transformed value

T_8 i.e. weed free check (3552 kg/ha), although it was at par with T_6 with a yield of 3522kg/ha. However, T_4 was further at par with T_6 . Significantly least SCY was recorded under weedy check (1918 kg/ha).

The results in the Table 1 indicated wide variation among treatments for weed dry matter as well as WCE. Pyrithiobac - sodium 62.5g a.i/ha + quizalofop-ethyl 50 g a.i/ha 20-30 DAS or 2-4 weed leaf stage + one hoeing) resulted in least weed dry matter (98.6 g/m^2) among chemical treatments. However, weed control efficiency was highest under T_8 i.e. weed free check (90.3%) followed by T_6 (71.0 %) and least under Farmer's practice (25.5%) among the evaluated treatments. Final weed count was also least (24.6) under T_6.Nadeem *et al* (2013) also reported significant differences for weed control efficiency with different weed control treatments.

Net returns (Rs.100916/ha) were maximum under T6. Cost of cultivation was also significantly highest for weed free check (T_8) owing to labour intensive inter culture work besides more picking charges incurred to pick the SCY. However, highest B:C ratio (2.14) was exhibited under T_6 closely followed by followed by (2.11). Contrarily, least B:C ratio (1.31) was observed for weedy check (T_{10}).

CONCLUSION

Among tested chemicals, pyrithiobac-sodium 62.5g a.i/ ha + quizalofop-ethyl 50g a.i/ha 20-30 DAS or 2-4 weed leaf stage + one hoeing was found to be promising for better weed management and realization of higher cotton productivity .

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Weed management practices with fertility levels on weed shift and economics of groundnut in fingermillet-groundnut cropping system

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Even though India ranks first in the world under groundnut area, there is need to import 8.03 million tons of edible oil. Cultivation of groundnut under rainfed conditions, lack of knowledge among the farmers with modern cultivation technology and improper fertilization, etc., are some of the causes of lower productivity of groundnut in India. Yield losses of groundnut due to weeds ranged from 13-80% (Ghosh *et al*. 2000).Therefore, an investigation to study the effect of weed management practices along with fertility levels in groundnut in groundnut - finger millet cropping system on weed flora, yield and economics was undertaken.

METHODOLOGY

Field experiment was initiated during *Kharif*, 2010 with finger millet - groundnut during 2010 to 2014at Main Research Station, Hebbal, University of Agricultural Sciences, Bengaluru. In groundnut, F1 - 75% NPK as fertilizer + 25% N as FYM, and F2 - 100% NPK as fertilizers only and W1 – PE pendimethalin 1.0 kg ai/ha, W2 –PE alachlor 1.0 kg ai/ ha and W3 - Hand weeding twice (20 and *40* DAS). Groundnut Cv. TMV-2 was taken up during summer 2010 to 2014 with RDF of 25 kg N, 75 kg P_20_5 and 38 kg K20/ha and common spacing of 30 cm x 15 cm. The pooled analysis was carried out for weed density/dry matter, pod yield and economics of the system was worked out.

RESULTS

Major weed species were *Cyperus rotundus, Cynodon dactylon, Digitaria marginata, Dactyloctenium aegyptium, Echinochloa colona, Commelina benghalensis, Euphorbia geniculata, Ageratum conyzoides, Borreria articularis, Amaranthus viridis and Acanthospermum hispidum.* Hand weeding at 20 and 40 DAS resulted in significantly lower weed density as compared to herbicide application. Similar trend was noticed with respect to weed dry weight. Application of pendimethalin resulted in lower weed density and dry weight as compared to alachlor. Similar results were reported by Dubey and Gangwar (2012).Interaction between sources of nutrients and weed management practices with did not significantly influence weed density and dry weight. Over five seasons, the pod yield was significantly higher with pendimethalin (1969 kg/ha) as compared to alachlor (1773 kg/ha), but comparable with hand weeded plots (2209 kg/ha), as result of good control of weeds particularly grasses. Under present conditions of labour scarcity and costly labour wages, imposing two hand weedings in groundnut at 20 and 40 DAS requires 50-women labourers at the cost of Rs.150 to 200 per day. Therefore, use of herbicides works out to be effective and cheaper as higher B:C ratio was obtained in herbicide treatments. Rao *et al.* (2011) have also reported similar results.

Table 1. Long term effect of herbicides on weeds, pod yield and economics in groundnut in groundnut- finger millet cropping system

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	Pod yield (kg/ha)	B : C Ratio
F1W1 - Pendimethalin + OM	(96.7)1.98	(40)3.14	2014	4.12
F1W2 - Alachlor + OM	(107.5)2.02	(46)3.44	1808	3.99
F1W3 - Hand Weeding + OM	(49.3)1.66	(12.2)1.93	2300	3.90
F2W1 - Pendimethalin – OM	(101.7)2.00	(45.3)3.20	1924	3.71
F2W2 - Alachlor – OM	(108.5)2.02	(46.5)3.39	1739	3.80
F2W3 – Hand Weeding – OM	(52.6)1.70	(13.7)2.02	2119	3.30
LSD (P=0.05)	NS	NS	NS	NA
F1 - 75% NPK + 25% N thro' FYM	(84.5)1.89	(32.8)2.84	2041	4.0
F2 – 100% NPK	(87.6)1.91	(35.2)2.87	1927	3.6
LSD (P=0.05)	NS	NS	NS	NA
W1 - Pendimethalin 1.00 kg ai/ha	(99.2)1.99	(42.6)3.17	1969	3.9
W2 - Alachlor 1.00 kg ai/ha	(108)2.02	(46.3)3.42	1773	3.8
W3 – HW (20 & 40 DAS)	(51)1.68	(13.03)1.97	2209	3.6
LSD (P=0.05)	0.04	0.17	108	NA

Data within the parentheses are original values, DAS: Days after sowing

CONCLUSION

Application of pendimethalin was the most effective in controlling weeds followed by alachlor. Hand weeding gave the higher pod yield compared to the herbicidal treatments but herbicidal treatments gave higher B:C ratio because of the high cost involved in the hand weeding.

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The efficacy of glyphosate monoammonium and other commercial herbicides to control volunteer oil palm seedlings in oil palm plantation

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Weeds have been identified as the major competitor to oil palm in the field for nutrients, space, light, and soil moisture thus affecting oil palm growth (Ismail and Chan, 2000). They interfere with the field operations resulting in the reduction of yield. Thick growth of noxious weeds may disturb daily field activities such as harvesting and evacuation of fresh fruit bunches, loose fruit collection, fertilizer application and other supervisory works. Interruption of loose fruit collection by weed infestation can contribute to more problems in managing weeds. Uncollected loose fruits will germinate and will eventually become weed themselves, termed as volunteer oil palm seedlings (VOPs). In addition, rotten bunches left in the field, the use of incomplete stripped empty fruit bunches as mulching material and seeds left in the field from the previous cultivation in replanting area will also lead to germination of VOPs. The sequential use of a single herbicide that eradicates grass weeds will also facilitate VOPs succession by giving space for growth.

A number of herbicides are available in the market to control weeds. Paraquat is one of the chemicals suggested to control VOPs in oil palm plantation. Chung (1996) had recommended spraying paraquat at 2.8 L/ha, sprayed wet to "run-off" (drench). Efficacy test by Ngim *et al.* (1995), found that paraquat at 110 ml per 18 litres water sprayed to completely wet, gave the best results to control VOPs. Glyphosate at 120 ml per 18 litres sprayed completely wet appeared to damage the growing points of the VOPs, resulting in retardation of the growth of the seedlings but did not kill the seedlings. Metsulfuron-methyl at 3 g per 18 litres, triclopyr at 20 ml per 18 litres, fluroxypyr at 15 ml per 18 litres and dicamba at 27 ml per 18 litres were not effective to control VOPs. Of late, there are a number of commercial herbicides available in the market claimed to have potential to control VOPs. However, the efficacy of these herbicides is not clear. Therefore, a study to evaluate commercial herbicides available in the market with potential to control VOPS has been carried out. For this study, eleven herbicide treatments were tested at the spray volume normally applied for general weed spraying (GWC) *i.e.*, 450 L/ha.

RESULTS

In this study, twelve treatments were evaluated – 11 commercial herbicides with potential efficacy against VOPs and a control. At 1, 2 and 3 DAA, no VOPs had been killed by any treatment. But at 7 DAA, paraquat dichloride at 5.0 L/ha (93% kill) and MSMA at 5.0 L/ha (20% kill) gave significant control of VOPs compared to other treatments (Table 1). At 14 DAA, there was 100% kill by glyphosate monoammonium at 5.0 L/ha followed by paraquat dichloride at 5.0 L/ha (93%, the same as at 7 DAA) and glyphosate isopropyl amine at 4.0 L/ha (70%). Others gave less than 50% kill or none at all. Both glyphosate herbicides appeared to have good efficacy to control VOPs. However, Ngim *et al*. (1995) reported that glyphosate 41% w/w at 3.0 L/ha sprayed at a volume of 450 L/ha (normally applied for GWC) gave only 8% and 9% control of VOPs at 7 and 14 DAA, and at 42 DAA, no control of VOPs was observed.

Herbicide and dose	% of VOPs killed #							
	7 DAA##	14 DAA	21 DAA	28 DAA	35 DAA	42 DAA	49 DAA	56 DAA
2,4-D isopropylamine 45% w / w at 2.5 L / ha	0c	10f	13h	17g	17f	37e	53cd	67c
Diuron 80% w / w at 1.0 kg / ha	0c	0g	3i	3h	3g	3f	3f	3e
Glufosinate ammonium 13.5% w / w at 3.3 L / ha	0c	40d	67d	67d	67d	67d	67c	67c
Glufosinate ammonium 5.8% w / w + imazapyr 5.5% w / w + 2,4-D 4.7% w / w	0c	0g	0i	0h	0g	0f	3f	3e
Glyphosate dimethylamine 52% w / w at 3.0 L / ha-	0c	0g	20gh	27fg	30e	30e	33e	33d
Glyphosate isopropylamine 41% w / w at 4.0 L / ha	0c	70c	87c	87c	87c	87c	87b	87b
Glyphosate isopropylamine 34% w / w + MCPA isopropylamine 6.5% w / w	0c	3g	30fg	33ef	40e	40e	40de	47d
Glyphosate monoammonium 33.6% w / w at 5.0 L / ha	0c	100a	100a	100a	100a	100a	100a	100a
Imazapyrisopropylamine 11.9% w / w 2.5 L / ha	0c	0g	0i	0h	0g	0f	0f	0e
MSMA 35.5% w / w at 5.0 L / ha	20b	27de	33ef	40e	40e	43e	43de	43d
Paraquat dichloride 13% w / w at 5.0 L / ha	93a	93b	93b	93b	93b	93b	93b	93b
Untreated (control)	0c	0g	0i	0h	0g	0f	0f	0e

#Means with the same letter in the same column are not significantly different according to Least Significant Difference (LSD) test at p= 0.05.; *##DAA = days after application*.

At 56 DAA, all herbicides killed more than 50% of VOPs except for glyphosate isopropyl amine + MCPA mixture at 3.0 L/ha (47%), MSMA (43%) and glyphosate dimethylamine 3.0 L/ha (33%). Treatments with diuron at 1.0 kg/ha, imazapyr isopropylamine at 2.5 L/ha and a mixture of glufosinate ammonium + imazapyr + 2,4-D at 1.2 L/ha were found to be ineffective to kill VOPs. Regrowth of treated VOPs were observed for all herbicides except for glyphosate monoammonium.

CONCLUSION

Glyphosate monoammonium (5.0 L/ha) and paraquat dichloride (5.0 L/ha) appeared to be the most effective herbicides to control VOPs less than 5 months old using knapsack sprayer at spray volume of 450 L/ha. VOPs treated with glyphosate monoammonium at 5.0 L/ha were completely controlled within 14 days. Glyphosate isopropylamine 4.0 L/ha gave good control of VOPs and the cost of this herbicide is much cheaper than glyphosate monoammonium even though it gave only 87% control of VOPs after 56 DAA. Based on this study, glyphosate monoammonium (5.0 L/ha), paraquat dichloride (5.0 L/ha), and glyphosate isopropylamine (4.0 L/ha)could be used to control VOPs using normal knapsack GWC spray volume at 450 L/ha.

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Effect of tank-mix application of tembotrione and atrazine onweed growth and productivity of maize

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Maize is the third most important cereal food crop of India after rice and wheat and is cultivated in an area of 8.11 million ha with a production of 19.77 million tones (Duriasamy*et al.* 2011).The crop is predominantly grown in *Kharif*(wet) season in India. Maize crop is infested with composite weed flora including grassy, broadleaved and sedgeswhich cause grain yield losses of 28–100% (Dass*et al.*2012). Herbicidesare the efficient tools for checking weed infestation in *Kharif* maize. But single application of one herbicide has seldom been found effective against complex weed flora throughout the critical period of competition. Mix application of herbicides is coming out as very essential tool to tackle the problem of complex weeds in many crops including maize. Tembotrione is a new selective post emergence herbicide recently introduced for use in maize mixing with herbicide atrazine. With this background the present experiment was conducted to study the effect of tank mix application of tembotrione and atrazine on weed growth and productivity of *Kharif* maize.

METHODOLOGY

A field experiment was conducted during *Kharif* season of 2014 at Agriculture farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal with maize variety *Kaveri Super 2020* to study the effect of tank mix application of tembotrione and atrazine on weed growth and productivity of *Kharif* maize. The experiment comprising of nine treatments *viz.*tembotrione at 80 g/ha + stefesmero surfactant 733 g/ha (T_1), tembotrione at 80 g/ha + stefesmero surfactant 733 g/ha + atrazine 500 g/ha (T_2), tembotrione at 100 g/ha + stefesmero surfactant (T_3), tembotrione at 100 g/ha + stefesmero surfactant 733 g/ha + atrazine 500 g/ha (T_4), tembotrione at 120 g/ha + stefesmero surfactant (T_5), tembotrione at 120 g/ha + stefesmero surfactant 733 g/ha + atrazine 500 g/ha (T_6), atrazine 1000 g/ha (T_7), handweeding at 25 and 40 DAS (T_8), unweeded control (T_9) was laid out in a randomized block design with three replications. The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. Data on density and dry weight of weeds, yield attributes and yield of maize were recorded during the growth period. Weed control efficiency (%) was computed using the dry weight of weeds.

RESULTS

The experimental field was infested with 9 species out of which *Cynodondactylon, Echinochloacolona,* among the grasses*; Cyperusiria,Fimbristylis miliacea* (among sedges) and *Ludwigiaparviflora, Commelinanudiflora* (among the broadleaved weeds) were predominant. The lowest density as well as dry weight of weeds at 60 DAS wererecorded with tembotrione at 120 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ha but it was at par with its application at 100 and 80 g/ha + stefesmero at 733 g/ha + atrazine 500 g/haand hand weeding twice with respect to weed dry weight (Table 1). Tembotrione at 120 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/haregistered the highest WCE closely followed by its application at 100 and 80 g /ha combined with atrazine at 500 g/ha.Weed infestation resulted 48% yield reduction in *Kharif* maize. Tembotrione at 100 g/ha + stefesmero at 733 g/ ha + atrazine 500 g/ha registered the highest number of kernels/cob, 500 kernel weight and grain yield of maize and was statistically at par with its application at 120and 80 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ha and hand weeding twice at 25 and 40 DAS. The treatment tembotrione at 100 g /ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ ha also recorded the highest gross andnet return closely followed by tembotrione at 120 g/ha + stefesmero at 733 g/ha + atrazine 500 g/ha and tembotrione at 80 g/ha + stefesmero at 733 g/ha + atrazine 500 g/ha (Table 1).

Table 1. Effect of treatments on density and dry weight of weeds, weed control efficiency, yield components, yield and economic return of *Kharif* maize

Treatment	Weed density (no./m^2) at 60 DAS	Weed dry weight (g/m^2) at 60 DAS	Weed control efficiency (%) at 60 DAS	No. of kernels /cob	500 kernel wt. (g)	Grain yield (kg/ha)	Gross return (Rs./ha)	Net return (Rs./ha)
Tembotrione at 80 g/ha + stefesmero surfactant at 733 g/ha	258.0	102.8	49.4	290.9	70.83	3450	41396	20291
Tembotrione at 80 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ha	63.7	21.9	89.2	376.7	80.61	4105	49260	27855
Tembotrione at 100 g/ha + stefes mero surfactant at 733 g/ha	210.3	88.2	56.6	303.1	72.50	3772	45264	23641
Tembotrione at 100 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ha	56.7	18.4	90.9	380.1	81.14	4577	54920	32997
Tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha	178.7	70.3	65.4	314.7	77.88	3808	45700	23592
Tembotrione at 120 g/ha + stefesmero surfactant at 733 g/ha + atrazine 500 g/ha	29.0	11.3	94.4	368.4	79.52	4315	51780	29372
Atrazine 1000 g/ha	78.0	26.2	87.1	307.7	74.06	3803	45632	25996
Hand weeding (25 and 40 DAS)	74.0	22.7	88.8	383.9	81.01	4522	54268	26052
Unweeded control	392.7	202.9	0	257.3	65.21	2379	28544	9508
LSD (P=0.5)	18.2	12.0	-	48.56	9.14	483.9	-	-

CONCLUSION

It may be concluded that application of tembotrione at 100 g /ha + stefesmero surfactant at 733 g /ha + atrazine 500 g /ha considerably reduced the weed infestation registering higher weed control efficiency, grain yield and net return of maize and was comparable with tembotrione at 80 g/ha + stefesmero surfactant at 733 g /ha + atrazine 500 g /ha and tembotrione at 120 g /ha +stefesmero surfactant at 733 g /ha + atrazine 500 g/ha.

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Technical Session 8

New herbicide molecules and products: the role of herbicide industry

Quelex™ herbicide (halauxifen-methyl + florasulam): a new post-emergent broadleaf weed herbicide product for China winter wheat production systems

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Four key broadleaf weeds – flix weed (*Descrainia Sophia*, DESSO), sherperd'sspurse (*Capsella bursa-pastoris*, CAPBP), cleaver (*Galium aparine*, GALAP), and chickweed (*Stellaria media*, STEME) are widely distributed in the winter wheat (*Triticum aestivum* L.) growing areas in China. Tribenuron has been used for over two decades for the control of these weeds; poor control and ALS resistance has been reported from numerous field locations (1 and 2). The pre-mixed cereal herbicide "Quelexä 20% WG formulation containing10% Arylex™ active (halauxifen-methyl) and 10% florasulam, is a newly developed product by Dow AgroSciences for use in wheat. The former is classified as synthetic auxin herbicide, and belongs to the new"Arylpicolinate" chemical family. It is very active on some broadleaf weeds; is selective to wheat, barley and oats; and can be used effectively in ALS resistant weed management programs (3). The latter, a triazolopyrimidine sulfonamide herbicide, inhibits cell division by inhibiting the plant enzyme acetolactate synthase (ALS) that is essential for the synthesis of the branched-chain amino acids valine, leucine, and isoleucine. In China, Quelex 20% WG efficacy and crop tolerance field trials were conducted in winter wheat from 2012 to 2014 demonstrated good to excellent control of many important broad leaf weeds including the four key broadleaf weeds mentioned above. This product is registered in China for use in winter wheat in 2014 and will provide an effective choice for ALS resistant weed management.

METHODOLOGY

Trials were conducted in winter wheat in China from 2012 to 2014.All trials utilized a randomized complete block design with 4 replicates and 20 m^2 plots. Weeds tested were *Capsella bursa-pastoris* (CAPBP), *Descraini asophia* (DESSO), *Stellaria media* (STEME), and *Galium aparine* (GALAP); and locally occuring weeds – *Lamium amplexicaule* (LAMAM), *Euphorbia helioscopia* (EPHHE), *Veronica persica* (VERPE) and *Lithospermum arvense* (LITAR). Brief information for the field trials is listed in Table 1. Herbicide applications were made in winter or early spring. For winter application, herbicides were sprayed in late November to middle December. For early spring application, they were applied in late February to middle March. A spray volume of 100 L/ha with flat fan nozzles was used for all trials. Herbicide treatments tested are listed in Table 2. Treatments varied among trials due to different target weeds. A non-ionic surfactant adjuvant –GF-2607 at 0.25% (v/v) based on Dow EcoSurf EH-9 was added to all Quelex and Arylex treatments.

Fresh weight of above ground parts of weeds were measured by random sampling at 3 spots using rectangle (0.25 m^2/spot) at 120 days after application(DAA) for winter application, and 45 DAA for early spring application, then was transformed into percent (%) control by Abott's formula (Ref ?). The data presented here are the mean values (% control) of weeds conducted in trial sites presented by boxplot.

RESULTS

Quelex 20%WG is a pre-mixed herbicide that consists of halauxifen-methyl and florasulam. Quelex 20% WG caused symptoms typical of ALS inhibitor herbicides and synthetic auxin-like herbicides resulting in immediate growth inhibition of susceptible plants. Research trials conducted from 2012-2014 generally indicated that Quelex 20% WG at 15-20 g/ha provided effective control of GALAP, DESSO, CAPBP, STEME, LAMAM,EPHHE, VERPE, and LITAR when sprayed in the winter, similar performance on these weeds when applied in early spring. Quelex 20%WG provided control of ALS resistant weeds and demonstrated no visual phytotoxicity in winter wheat.

For CAPBP control, Quelex 20% WG at 15-20 g/ha gave acceptable control (about 85%-92%) at 120 DAA in winter applications. The performance was similar to the commercial standardize tank-mixture of florasualm and carfentrazone at 9 + 15 g/ha respectively. For early spring applications, Quelex 20% WG at 10-20 g/ha provided excellent CAPBP control (over 95%) at 45 DAA, giving slightly better performance than the commercial standard. Tribenuron at 22.5 g/ha provided poor control of CAPBP for winter application and early spring application. CAPBP resistance to tribenuron at Zhumadian, Henan has previously been reported. Apparently Quelex 20%WG provided effective control of ALS resistant CAPBP in either winter or spring application.

For DESSO control, Quelex 20%WG at 10-20 g/ha gave over 95% controls in winter application, similar to the tank-mixture of florasualm and carfentrazone at 9 + 15 g/ha. The product at 15-20 g/ha provided similar control of DESSO (greater than 94%) when applied in early spring application. Tribenuron at 22.5 g/ha gave only 40.7% control of DESSO when applied in winter, and gave 87.6% control when applied as an early spring application. Quelex 20%WG demonstrated effective control of both ALS susceptible and resistant biotypes of DESSO.

Quelex 20%WG at 10-20 g/ha provided acceptable control of STEME at both timings with a clear dose response in each case, but gave slightly lower performance than the commercial standard: the tank-mixture of florasulam + fluroxypyr + carfentrazone at 9 + 90 + 22.5 g/ha. The commercial standard provided complete control on STEME in both winter and spring application. Arylex 7.5% (halauxifen-methyl alone) at 7.5 g/ha gave moderate control. Florasulam alone at 7.5g gave less than 90% control. The addition of florasulam to halauxifen-methyl improved the performance. Quelex 20%WG provided acceptable control against STEME, but levels of control were less than that provided by the commercial standard.

For *Galium aparine* (GALAP) control, Quelex 20% WG was tested only in early spring. Quelex 20% WG at 6-15 g/ha with or without GF-2607 adjuvant provided excellent control of GALAP at 45DAA.

For locally occurring weeds, Quelex 20%WG at rate of 10g/ha providedexcellent control (100%) of *Lamium amplexicaule* (LAMAM) in both winter and spring applications. For the control of *Euphorbia helioscopia* (EPHHE) and *Veronica persica* (VERPE), Quelex 20% WG at 15-20 g/ha provided acceptable control in winter application, but the performance when applied in early spring was not acceptable (40-60% control). *Lithospermum arvense* (LITAR) is a deep-rooted weed that is highly adaptable and is not

Table 1. Information of field trials conducted with Quelex™ 20% WG in winter wheat growing season during 2012 to 2014 in China.

Weeds	Application timings	Number of trials	Temperature at application	Wheat growth stage (Zadoks)	Trial locations
CAPBP	Winter	4	1-9ºC	14-16	Jiangsu, Hebei, Shaanxi
	Early spring	3	3-13ºC	18-19	Jiangsu, Hebei, Shaanxi
DESSO	winter	1	1-9ºC	14-16	Hebei
	Early spring	1	3-13ºC	18-19	Hebei
STEME	winter	2	1-10ºC	14-16	Jiangsu, Anhui
	Early spring	1	5-17ºC	22-23	Anhui
GALAP	winter				
	Early spring	1	3-13ºC	22-23	Jiangsu
LAMAM	winter	2	1-9ºC	14-16	Anhui, Henan
	Early spring	2	3-13ºC	22-23	Anhui, Henan
EPHHE	winter	2	1-10ºC	14-18	Anhui, Henan
	Early spring	1	3-10ºC	24-26	AnhuiHenan
VERPE	winter	2	1-10ºC	14-18	Anhui,
	Early spring	2	3-10ºC	23-25	Anhui,
LITAR	winter	1	1-10ºC	14-16	Anhui
	Early spring	1	4-17ºC	16-19	Anhui

effectively controlled by commonly used herbicides. While Quelex 20% WG at 15-20 g/ha provided effective control of LITAR in winter applications, 20 g/ha of product was required to give acceptable LITAR control in the spring.

CONCLUSION

In summary, Quelex 20% WG at 15-20 g/ha provided effective control on *Capsella bursa-pastoris*, *Descrainia sophia*, *Galium aparine* and *Stellaria media* when applied in the winter. It provided somewhat less control of *Stellaria media* compared with the commercial standard: florasulam + fluroxypyr + carfentrazone. The same trend was observed in early spring applications. Quelex 20% WG at 10-20 g/ha gave excellent control of *Lamium amplexicaule* in both winter and spring applications. For *Lithospermum arvense*, *Euphorbia helioscopia*, and *Veronica persica*, Quelex20% WG at rate of 15 g/ha and above gave acceptable control in winter applications, but provideds omewhat less control in spring applications. There was no crop injury symptoms observed in any field trials with Quelex treated plots.

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Table 2. Chemicals used in field trials

Chemicals	Rates (g or /ha)
Quelex™ 20% WG (halauxifen-methyl + florasulam, 100 + 100 g/kg)	10, 15 & 20
Arylex™ (halauxifen-methyl) 7.5 g/l	7.5
Florasulam 50g/l + carfentrazone 100 g/kg	9+15
Florasulam 50g/l + fluroxypyr 200 g/l + carfentrazone 100 g/kg	9+90+22.5
Florasulam 50g/l	7.5
Tribenuron 750 g/kg	22.5

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Zeozyme and Lanthanum doped nano particle embedded in a polystyrene film - As photocatalyst for degradation of diuron in ecosystem

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The photocatalytic degradation of pollutants in ecosystem was achieved by Zeolite-Na-Y and Lanthanum ions doped TiO_2 (1:5) embedded into Polystyrene film. Photocatalytic film were synthesized and used as photo catalyst for reducing the toxicity of diuron in water, using sunlight as a source .The solid support was modified with different ratios of Zeolite and Lanthanum doped nanoparticle .The hydrophobic nature of the polymer support was utilized for the heterogeneous system. Catalyst characterization was done by, FT-IR,XRD, AFM ,DRS-UV, BET and SEM-EDAX.Analytical results reveal the successful loading of Zeolite-Na-Y and Lanthanum ions doped TiO_2 .AFM and the BET results concludes the increase in the surface area of the catalyst. The Photocatalytic conditions were carried out at 20 mg/L, with initial concentration at its pH , 0.01M H_2O_2 and catalytic amount of 500 mg/L was loaded in the fish tank (60 x 30 x 45cm, lbh) in the absence of fish without stirred condition. The dissipation of the diuron was 60% after 2hours, when the loading of Zeolite-Na-Y and Lanthanum ions doped TiO_2 was (1:5). The optimized ratio yielded good results and the same film models were used in presence of fish are the noteworthy features. The reusability of the prepared photocatalytic film was successfully examined six times with out any appreciable loss in catalytic activity.

Efficacy of Assert™ herbicide against weed flora in transplanted rice

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Rice is one of the most important food crops of India. Rice productivity is very low in India and weeds pose serious menace to yield. The weed flora under transplanted conditions is very diverse and consists of grass, sedge, and broadleaf weeds causing yield reduction of rice crop up to 76% (Singh *et al*. 2004). Chemical control is the most commonly used and reliable method for controlling weeds in rice. Pre-emergence herbicides used in rice demand ample water availability and have performance issues if growers fail to maintain adequate water in the field after application. Thus growers need to perform multiple manual hand weedings and/ or apply post-emergence herbicides. Taking into consideration the necessity of post-emergence chemical weed control for stable rice production, Assert™ herbicide, a new post-emergence rice herbicide, was evaluated in transplanted rice. Assert contains penoxsulam (25 g/L), a proprietary herbicide of Dow AgroSciences, and is based on a unique oil dispersible (OD) formulation.

METHODOLOGY

Thirteen field trials were conducted during 3 crop seasons (*Kharif* 2012, *Rabi* 2012 and 2013, and *Kharif* 2013) in India across various sites in Haryana, Punjab, West Bengal, Andhra Pradesh, Telangana, and Chhattisgarh to evaluate the efficacy of Assert against weeds in transplanted rice. Different Assert doses (20, 22.5, and 25 g/ha) were compared with bispyribac-sodium (10% SC), azimsulfuron (50% DF), and untreated plots. All treatments were applied at the 4 to 8 leaf stage of target weeds and were arranged in a randomized block design with three replications. Knapsack sprayers fitted with flood jet nozzle were used to apply the treatments. Normal agronomic practices were followed for the crop as practiced by farmers. Weed density (No. plants/m^2) by species was observed at 25-30 days after treatment application. Weed density was subjected to percent abbot transformation to calculate percent control compared to untreated plot weed count (Ref ?).

RESULTS

Dominant weed flora in the experimental fields consisted of grasses (*Echinochloa crus-galli* and *E. colona),* sedges *(Cyperus difformis* and *Scirpus* sp.*),* and broadleaves *(Alternanthera* sp., *Ludwigia* sp., *Monochoria vaginalis* and *Sphenoclea zeylanica).* Assert at 22.5 g/ha provided control of *E. crus-galli* (98%) that was similar to the control provided by bispyribac-sodium (99%) and superior to the control provided by azimsulfuron (78%) over weedy check (Table 1). Similar results were observed for *E. colona* where Assert provided 88% control, bispyribac-sodium provided 87% control, and azimsulfuron provided 41% control. For sedge weeds found in experimental fields, Assert at 22.5 g/ha provided weed control that was superior to bispyribac-sodium (87 to 89% control versus 58 to 78% control) and similar to azimsulfuron (91 to 95% control). For broadleaf weeds, the weed control provided by Assert (81-96% control) was found to be equivalent to the weed control provided by both bispyribac-sodium (71-96% control) and azimsulfuron (81 to 100% control).

Table1. Percent control of major weeds in transplanted rice at 25-30 DAA averaged across three seasons)

Treatment	Assert		Bispyribac-sodium		Azimsulfuron
	Dose (g/ha)				
	20	22.5	25	25	37.5
Grasses					
Echinochloa crus-galli	88	98	99	99	78
E. colona	81	88	88	87	41
Sedges					
Cyperus difformis	70	85	89	58	91
Scirpus spp	75	88	87	78	95
Blws					
Alternanthera spp	89	92	96	96	NA
Ludwigia spp	71	77	81	71	81
Monochoria vaginalis	81	91	93	83	81
Sphenoclea zeylanica	77	87	93	92	100

[1] Penoxsulam (25 g/L)

CONCLUSION

Assert is a new post-emergence broad-spectrum herbicide from Dow AgroSciences. It contains penoxsulam at 25 g/L and is based on unique oil dispersible (OD) formulation. Once registration approval is granted by the regulatory authorities of India, Assert™ herbicide will be the first rice OD formulation herbicide launched. Its efficacy potential at 22.5-25 g/ha will provide rice growers with superior weed control and excellent crop safety as compared to existing herbicides.

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Rinskor™ Active: Discovery and development of a new rice herbicide from Dow AgroSciences

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Weeds developing herbicide resistance in rice (*Oryza sativa* L) has increased in frequency and the utility of some herbicides; and herbicide modesofaction has diminished resulting in the inability to effectively control some weeds with current herbicide technologies. *Echinochloa* weed species are a major constraint to rice production worldwide and have developed resistance to many of the current herbicides previously used for effective weed control (Heap 2015). The current and developing weed control issues in rice led Dow AgroSciences to pursue a new herbicide that would provide an alternative modeofaction for the control of existing target site resistant species, including *Echinochloa* sp. Research efforts resulted in the discovery and development of Rinskor, a herbicide which will provide an alternative modeofaction for the control of certain grass, sedge and broadleaf weeds in rice.

METHODS

Standard laboratory, greenhouse, and field techniques were utilized to evaluate the herbicidal and edaphic properties of Rinskor. Completed and continuing field trials, first initiated in 2010, resulted in over 1000 global field trials contributing to the understanding of the agronomic utility of Rinskor. To analyze the physiological mode of action and site of action for Rinskor, whole plant studies on wild type and mutant *Arabidopsis thaliana* (ARBTH), a test species, were conducted in conjunction with surface plasmon resonance (SPR) molecule-protein interaction studies of the auxin binding proteins TIR1 and AFB5. Mutants harbored amino acid nonsense changes in AFB5.

RESULTS

The discovery of Rinskor started with a retrospective search of the arylpicolinate chemistry focused on broad-spectrum weed control and utilized structure-activity relationships and biological characterization to identify the desired molecule. Common use rates are 5-50 g/ha depending on use pattern and target species. Key species controlled within defined use patterns include: *Echinochloa crus-galli; Echinochloa colonum; Echinochloa oryzoides; Urochloaplantaginea; Urochloaplatyphylla; Leptochloachinensis; Cyperus difformis; Cyperus iria; Cyperus rotundus; Fimbristylis miliacea;Aeschynomene sp.;* [1.]*Amaranthus sp.; Ambrosia sp.; Chenopodium album; Conyza sp.; Heteranthera sp.; Ludwigia octovalis; Monochoria vaginalis; Sagittariatrifolia; and Sesbaniaexaltata*. When used at anticipated label instructions, rice show excellent crop tolerance and no impact on yield has been observed. When transitory rice injury is observed, it manifests as "onion-leafing" or minor growth reduction.

The herbicidal activity of Rinskor™ active dissipates quickly in soil and tolerant plant tissue. No restrictions are anticipated in planting any rotational cropafter an application of Rinskor in rice (Heap 2015). Foruse in foliar applications, a NeoEC™ formulation has been developed for Rinskor. This Neo EC formulation does not contain petroleum distillates, is low in volatile organic compounds (VOCs), contains the necessary adjuvant and will be utilized at 1-1.2 l/ha (25 to 30 g/ ha).

As compared to other auxin chemotypes, Rinskor and other arylpicolinates demonstrate novel characteristics in terms of use rate (some species are controlled at less than 5 g/ ha), spectrum (grass, broadleaf and sedge activity), environmental fate (rapid degradation of herbicidal activity in soil and plants), and molecular interaction (unique auxin receptor binding). Rinskor has demonstrated a unique spectrum of activity and the ability to control ALS-, ACCase-, propanil-, and quinclorac-resistant grass, sedge, and broadleaf species.

In laboratory modeofaction studies,AFB5 mutant *Arabidopsis thaliana* plants were 10-33 fold less sensitive to Rinskor than wild-type (WT) *Arabidopsis thaliana* plants depending on the mutant line [based on 50% growth reduction (GR_{50}) values of plant dry weight]. Wild-type *Arabidopsis thaliana* plants and AFB5 *Arabidopsis thaliana* mutant plants exhibited similar sensitivity to 2, 4-D with GR_{50} values of 2.2 g/ha and 2.7-9.9 g/ha respectively.The resistance of ARB5 *Arabidopsis thaliana* mutant plants to Rinskor and the susceptibility of the same AFB5 *Arabidopsis thaliana a*mutant plants to 2,4-D suggests that the molecular recognition site for Rinskor™ Active is the AFB5 receptor. Further support for this assertion was obtained by SPR analyses which indicated a stronger affinity of Rinskor to AFB5 over TIR1. The whole plant mutant studies and protein specific interaction analysis indicate that Rinskor is an auxin herbicide with high affinity to the AFB5 protein which differentiates Rinskor from 2, 4-D.

CONCLUSION

Rinskor is a new arylpicolinate herbicide currently indevelopment by Dow AgroSciences with global utility in rice (seeded and transplanted) and other crops. Rinskor will offer an alternative modeofaction herbicide for the control of grass, broadleaf, and sedge weeds in rice and provide control of existing target site resistant species. First registrations of Rinskor are anticipated in 2017 to 2018.

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Efficacy of Vivaya™ herbicide against weed flora in different rice cultures in India

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Rice (*Oryza sativa* L.) in India is grown primarily by manual transplanting of seedlings into puddled soil. Due to labor and water scarcity, the trend towards direct-seeded rice has increased. Due to this increasing shift in crop culture, weed infestations have become more prominent and a constraint in rice production system. Higher weed infestation including aerobic weeds is a major constraint in the adoption of direct-seeded rice (Rao *et al.* 2007). The same phenomena are being observed in water deficient transplanted paddy ecosystems. Since the available post- emergence herbicides do not provide reliable control for all the weeds, growers need to either tank-mix or utilize multiple applications of herbicides to achieve satisfactory weed control. Taking into consideration the need for new post-emergence chemical weed control solutions for complex weed flora in rice, Vivaya™ herbicide was evaluated in transplanted and puddle direct-seeded rice. Vivaya consists of a pre-mix of penoxsulam (10 g/l) plus cyhalofop (50 g/l) based on a unique oil dispersible (OD) formulation.

METHODOLOGY

Field experiments were conducted during 3 crop seasons (*Kharif* 2011, *Rabi* 2011 and 2012, and *Kharif* 2012) in India across various sites (Haryana, Punjab, West Bengal, Andhra Pradesh, Telangana, and Chhattisgarh) to evaluate the efficacy of Vivaya against weeds in transplanted (17 trials) and direct-seeded (16 trials) rice. Different doses of Vivaya (120 and 135 g/ha) were compared with bispyribac-sodium (10% SC), azimsulfuron (50% DF), and a tank-mix of bispyribac-sodium + fenoxaprop (25 and 60.4 g/ha**)**. All treatments were applied at the 4-8 leaf stage of weeds and were arranged in a randomized block design with three replications. Knapsack sprayers fitted with flood jet nozzle were used to apply the treatments. Weed density (no plants/m^2) by species were observed at 25 to 30 days after application (DAA). Weed count was subjected to percent Abbot transformation to calculate percent control compared to untreated plot weed count (Tables 1 and 2).

RESULTS

The research field sites were heavily infested with grass weeds (*Echinochloa crus-galli, E. colona, and Leptochloa chinensis),* sedge weeds *(Cyperus difformis* and *Scirpus* sp.) and broadleaf weeds (*Ammannia* sp., *Ludwigia* spp, *Monochoria vaginalis, Sphenoclea zeylanica, Marsilea* sp.

Alernanthera sp., *and Sagittaria* sp.*)*. Vivaya™ herbicide at 135 g/ha provided control of *Echinochloa* sp. equivalent to the tank-mix of bispyribac-sodium + fenoxaprop and superior to azimsulfuron. Vivaya at 135 g/ha provided superior control of sedges as compared to bispyribac-sodium alone and in mixture with fenoxaprop and similar to azimsulfuron. For broadleaf weed control, Vivaya was found equivalent to both bispyribac-sodium and azimsulfuron. Similar results were observed in direct-seeded rice, except Vivaya at 135 g/ha provided superior control of *L. chinensis*.

CONCLUSION

Vivaya™ herbicide is a new broad-spectrum pre-mix herbicide from Dow AgroSciences consisting of penoxsulam plus cyhalofop (10 + 50 g/l) in a unique oil dispersible (OD) formulation with adjuvant built in. Its efficacy potential at 135 g/ha will provide rice growers a new option for superior control of complex weed flora of grass, sedge, and broadleaf weeds found in different rice cultures as well as excellent crop safety.

Table 1. Percent control of major weeds in transplanted rice at 25 to 30 DAA averaged across three seasons

Treatment	Vivaya		Azimsul-furon	Bispyribac-sodium	Bispyribac-sodium + Fenoxaprop
	Dose (g/ha)				
	120	135	37.5	25	25+60.4
Grasses					
Echinochloa. crus-galli	84	93	63	93	99
E. colona	82	94	35	86	92
Sedges					
Cyperus difformis	84	91	91	73	73
Scirpus spp	84	90	100	84	97
Blws					
Ammania spp	65	71	64	62	68
Ludwigia spp	73	75	76	77	78
Monochoria vaginalis	90	91	87	80	81
Sphenoclea zeylanica	80	91	91	87	85
Marsilea spp	93	100	99	88	85
Alternanthera spp	79	94	86	83	77
Sagittaria spp	100	100	100	100	100

Table 2. Percent control of major weeds in puddle direct-seeded rice at 25-30 DAA averaged across three seasons

Treatment	Vivaya		Bispyribac-sodium	Bispyribac-sodium + Fenoxaprop
	Dose (g/ha)			
	120	135	25	25 + 60.4
Grasses				
Echinochloa crus-galli	77	95	NA	86
E. colona	79	89	85	87
Leptochloa chinensis	76	91	56	82
Sedges				
Cyperus difformis	86	91	82	84
Scirpus sp.	100	100	87	NA
Broad Leaf Weeds				
Ludwigia sp.	61	79	75	71
Monochoria vaginalis	91	98	81	78
Sphenoclea zeylanica	90	94	87	81
Sagittaria sp.	75	79	78	79

Penoxsulam (10 g/l) plus cyhalofop (50 g/l)

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Development and global utility of penoxsulam in rice

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Weeds in rice are a global production problem. It has been calculated that global rice utilization is increasing faster than rice production, resulting in a reduction of global rice stocks over the last several years (Rice Market Monitor, 2015). Rice acreage is steady to slightly increasing, but production is not increasing as fast as utilization. As rice is a key global staple for human consumption, it is important that rice is produced as efficiently as possible to maximize yields. Globally, rice growers are coming to understand that to maximize yields, and potentially their profits, that they have to invest in crop protection products that protect yields. A key success factor to maximizing rice yields is the control of weeds that rob the rice crop of water, nutrients and sunlight. Less than 5% of global rice production is traded across borders, demonstrating the internal value and country dependence on rice production. Rice growers are increasingly using more and better pesticides in the process of intensification to protect and maximize rice yields and to maintain economic viability.

There are many issues today that rice farmer's face on a global basis to grow a productive and economical rice crop. These issues include the reduction in availability of water at one or more periods during the rice life cycle to effectively grow the crop to its full yield potential, reduced availability of labor to perform key tasks to ensure a successful crop (such as hand transplanting or hand seeding rice, hand weeding, applying pesticides at the correct time and rate to control the pests and protect the crop, managing water, etc.), and herbicide resistance when there are few options for herbicides to control the key yield robbing rice weeds. The overuse of the existing herbicide products, such as those with acetolactate synthase inhibitor (ALS) mode of action, ACCase mode of action, quinclorac, propanil, *etc.,* without appropriate herbicide mode of action rotation, can accelerate the development of herbicide resistance.

Penoxsulam is a rice herbicide used globally to help rice growers control economically important weeds and thus can help to maximize yields. Penoxsulam is the 6th triazolopyrimidine sulfonamide herbicide (Figure 1) developed by Dow AgroSciences (Johnson 2007, 2009).

The original hypothesis for this area of chemistry was focused on testing bioisosteres of the original sulfonyl urea herbicides (Kleschick 1990). The first triazolopyrimidine sulfonamide developed from this area of research was flumetsulam, which controlsmany broadleaf weeds in soybean and corn, but does not control grasses (Subramanian 1991). Metosulam controls broadleaf weeds in corn. Diclosulam and cloransulam-methyl control broadleaf weeds and some sedge in soybean and sugar cane. Florasulam was the first sulfonamide developed that controlled broadleaf weeds in cereals (primarilywheat and barley). None of these sulfonamides control any grass weeds (Johnson 2012). Penoxsulam is unique in that it was the first sulfonamide that is selective to a grass crop (rice, *Oryza sativa*) and controls a key grass weed (*Echinochloa* spp.) in rice and many other broadleaf and annual sedge weeds (Mann 2005). Pyroxsulam was developed primarily for use in cereals (wheat and barley) to control grass and broadleaf weeds, but requires use of a safener to protect cereal crops from injury (Johnson 2012).

The evolution of triazolopyrimidine sulfonamide chemistry leading up to the discovery of penoxsulam, from initial greenhouse screening, structure activity relationships (SAR) and field screening of several key candidate analogs leading to its identification and development is well documented (Johnson 2009, 2012). Key customer attributes that drove the biological SAR testing for the selection of penoxsulam for use in rice included: requirements for commercially acceptable rice selectivity in Indica and Japonica rice control of the key global rice weed (*Echinochloa* spp.); control of many other broadleaf and sedge weeds; significant residual weed control activity on key rice weeds; and the flexibility to be used in direct-seeded, water-seeded and transplanted rice as an in-water or post-emergence application.

Several key attributes demonstrated by penoxsulam in rice that have made it successful on a global basis include broad spectrum weed control of annual grasses (*Echinochloa* spp.), broadleaf, and sedge weeds (Table 1);up to 2 to 3 weeks of residual weed control for some key rice weeds in many countries; utility in all rice types including direct-seeded, water-seeded and transplanted rice; utility in Indica and Japonica rice; and formulation flexibility (SC, OD and granule formulations, as well as the ability to be formulated in several pre-mixes) to meet different customer needs. Additionally, the ALS mode of action with low use rates and excellent toxicology and ecotoxicology profile was important for global utility.

From a post-emergence perspective, penoxsulam must be applied with an adjuvant to provide effective weed control. In countries where adjuvants are readily available and their use is common practice, the suspension concentrate (SC) formulation was developed. In other countries, such as Europe and Asian Pacific, quality adjuvants that are needed to ensure the weed control activity of penoxsulam are not readily available at the rice grower level, so several oil dispersion

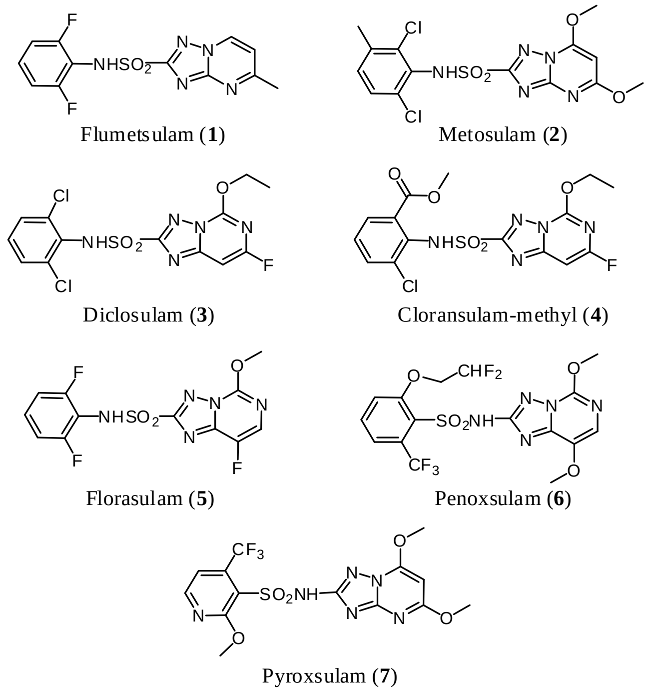

Fig. 1. Sulfonamide Herbicides Developed by Dow AgroSciences LLC.

(OD) formulations were developed that contained a built-in adjuvant to ensure good weed control. Depending on the local cultural practices, the weed spectrum to be controlled and the application technology available to the rice grower, penoxsulam can be applied in all major rice growing countries with the local application technology, which includes back-pack sprayers, as a sand-mix or fertilizer-mix application, tractor application, and aerial (airplane or helicopter) application.

Penoxsulam is currently registered for use in rice in over 35 countries for the selective control of weeds in rice. Penoxsulam was first launched globally in 2005 and by 2014estimated use was on over 10 million ha of rice (personal observation). Penoxsulam is also registered and used for weed control in turf, vines, aquatics, sorghum, and tree nut orchards primarily for control of broadleaf weeds.

As a rice herbicide, penoxsulam has many attributes that make it very useful to rice growers. Depending on local herbicide use practices and label recommendations, penoxsulam can be applied pre-emergence or post-emergence to the crop and weeds. As a "post-emergence" application to the weed foliage, it can be applied in-water or post-emergence to foliage of existing, susceptible weeds to provide commercial levels of weed control.

Penoxsulam is absorbed by the foliage, stems, and roots and is a systemic, xylem and phloem mobile active ingredient (Mann 2005). Penoxsulam is registered for "pre-emergence" control of many of the weeds that it controls from a post-emergence perspective. Depending on the country and the weed spectrum, use rates vary around the world, but typical post-emergence use rates in Asian countries are in the range of 10-15 g/ha, whereas use rates in China use 20-37.5 g/ha, and use rates in India are 20-22.5 g/ha. In North America and South America, use rates vary from 30-50 g/ha, whereas in Europe and MEAF countries the use rates vary from 20-40 g/ha. While the difference in use rates between countries is not well understood, it is hypothesized that the use rate differences may be due to differences in environmental factors (temperatures, water management, soil factors, etc.), differences in weed spectrums and weed sizes to be controlled between countries, and potentially some biotype differences within a species between geographies that have evolved over time.

Penoxsulam provides pre-emergence and post-emergence control of the globally important rice grass weeds *Echinochloa* species, as well as many other broadleaf and annual sedge weeds. To control other "commercially" important weeds that are important to rice growers several pre-mixtures have been developed to broaden the weed control spectrum. Key pre-mixtures that are commercialized include: cyhalofop-butyl to additionally control other annual grass weeds including *Leptochloa chinensis, Brachiaria* sp., *Panicum* species, and *Paspalum* species in rice (herbicides such as TopShot™ in Asian countries, Ricer™ in China, Vivaya™ in India, and RebelEX® in USA); triclopyr to control *Ipomoea* sp., *Alternanthera* sp., and some *Scirpus* sp. in rice (Grasp® Xtra in USA and Ricer™ Xtra in Uruguay); and oxyfluorfen for the broad-spectrum control of broadleaf weeds including glyphosate-resistant *Conyza* species in tree nut orchards (Pindar® GT in USA).

Due to the excellent tolerance of rice to penoxsulam and the pre-emergence weed control activity afforded by penoxsulam in many countries, new pre-emergence and mixture product concepts are being developed to broaden the utility of penoxsulam to rice growers. Penoxsulam is now commercialized as a pre-emergence herbicide in transplanted and seeded rice in several countries (Granite™ SC in India and Nong Di Long™in China), and new pre-mixturesare being developed that include penoxsulam + butachlor (Rainbow™ 410SE in Indonesia and DaoYou™ in China). The new pre-emergence pre-mixtures provide longer and broader spectrum, residual herbicide weed control as compared to the single active ingredients when applied pre-emergence to the weeds, thus providing additional tools for rice growers to control commercially important weeds.

Table 1. Weeds Controlled by Penoxsulam.

Alternanthera philoxeroide	*Echinochloa polystachy*	*Polygonum* spp
Amaranthus spp	*Eclipta alba*	*Rotala indica*
Ammannia spp	*Eleocharis* spp	*Sagittaria* spp
Bidens triparta	*Fimbristylis* spp	*Scirpus juncoides*
Conyza spp	*Heteranthera limosa*	*Scirpus mucronatus*
Cyperus spp (annual)	*Lindernia* spp	*Sesbania exaltata*
Echinochloa crus-galli	*Monochoria* spp	*Sphenoclea zeylanic*

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Discovering new herbicide by utilizing intermediate derivatization

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Soaring agro-economy as well as greater inputs into weed management has induced growth of the herbicide market. New herbicides with novel structure and mode of action are therefore required. Methods for discovering agrochemical lead compounds are Random Synthesis and Screening, Modification of Natural Compounds, Me Too Chemistry, Combinatorial Chemistry, and Rational Design. Conventional methods lack the required efficiency for sustained success, and the recent methods, reported in pharmaceutical field, have not yet been successful for discovering agrochemicals. Guan et al. [2014] reported a practically useful and efficient strategy and introduced Intermediate Derivatization Methods (IDMs) for agrochemical discovery. The approach fit between the conventional methods used in agrochemical discovery and the recent novel methods reported in the pharmaceutical field. It applies a wide variety of synthetic methodology on key intermediates resulting in an efficient route to innovative chemical structures, which, in conjunction with biological screening, become patentable leads or target compounds. Following three types of IDMs depending on the functionality in the key intermediate are: (a) Common Intermediate Method: modification of key intermediates used as building blocks that possess functionality amenable to preparing a diverse set of structures; (b) Terminal Group Replacement Method: modification of key intermediates that possess functionality amenable to replacing terminal moieties of existing agrochemicals (c) Active Compound Derivatization Method: modification of known active compounds possessing functionality amenable to derivatization.

The chalcones are the key intermediates used as building blocks for numerous bioactive molecules. These provide new class of biocides due to the pharmacologically active moiety and various biological activities. The chalcones are 1,3 - diarylprop - 2 - en - 1 - one, form a broad class of compounds containing two aromatic rings bound with vinyl ketone fragment. Chalcones are useful intermediates for obtaining the variety of heterocycles and heterocyclic pesticides. They are naturally occurring plant metabolites possess a broad spectrum of biological activities such as cancer cell lines, antimitotic, anti-inflammatory, hepatoprotective, molluscicidal properties, heme oxygenase-1, antimicrobial. This broad spectrum of applications encouraged us to search for another addition to the existing reported usage.

A series of chalcones were synthesized by condensation of aromatic aldehydes with aryl ketones at room temperature in one step. All the compounds were characterized on the basis of their TLC, IR, ^{1}H NMR, ^{13}C NMR spectroscopic data and elemental analysis. The compounds were initially screened *in vitro* for testing their herbicidal activity against mustard (*Brassica juncea* L. Coss) and chickpea (*Cicer arietinum* L.).

The data were analyzed by the analysis of variance (ANOVA) following Duncan's multiple range test in SPSS computer software. A field study with four crops namely, pearl millet (*Pennisetum typhoides* L.), soybean (*Glycine max* L. Merrill), green gram (*Vigna radiata* L. Wilczek) and maize (*Zea mays* L.) proved the efficacy of the herbicide against various annual grass and broad-leaved weeds, and selectivity to these crops when applied as pre-emergence with a volume rate[a] of 400 l/ha at 500 g/ha.

Based on J values the protons around the double bond were in trans (E) configuration. Analysis of variance showed insignificant difference between all the synthesized chalcones, and some were effective against the target broad leaf weeds. *In vitro* study revealed that certain compounds had significant effect on the germination of test seeds. The halogen substituted compound showed potent herbicidal activity, which could inhibit the growth of both roots and shoots at 50 µg/ml. Field trails proved that there is hardly any phytotoxicity effect to any crops at recommended dose. Formulation[a] 2X is more effective against weeds than X dose but proved to be more toxic to soybean crop than maize.

Chalcones have an opportunity to behave as potent herbicidal agents and have excellent scope for further chemical modification to optimize it to be a candidate for new herbicide molecule.

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Zeozyme and lanthanum doped nanoparticle embedded in a polystyrene film - As photocatalyst for degradation of diuron in ecosystem

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The photocatalytic degradation of pollutants in ecosystem was achieved by Zeolite-Na-Y and Lanthanum ions doped TiO_2 (1:5) embedded into Polystyrene film. Photocatalytic film were synthesized and used as photo catalyst for reducing the toxicity of diuron in water, using sunlight as a source .The solid support was modified with different ratios of Zeolite and Lanthanum doped nanoparticle .The hydrophobic nature of the polymer support was utilized for the heterogeneous system. Catalyst characterization was done by, FT-IR, XRD, AFM, DRS-UV, BET and SEM-EDAX. Analytical results reveal the successful loading of Zeolite-Na-Y and Lanthanum ions doped TiO_2 .AFM and the BET results concludes the increase in the surface area of the catalyst. The Photocatalytic conditions were carried out at 20 mg/l, with initial concentration at its pH, 0.01M H_2O_2 and catalytic amount of 500 mg/L was loaded in the fish tank (60 x 30 x 45cm, lbh) in the absence of fish without stirred condition. The dissipation of the diuron was 60% after 2hours, when the loading of Zeolite-Na-Y and Lanthanum ions doped TiO_2 was (1:5). The optimized ratio yielded good results and the same film models were used in presence of fish are the noteworthy features. The reusability of the prepared photocatalytic film was successfully examined six times without any appreciable loss in catalytic activity.

Technical Session 9

Weed management options for crops and cropping systems (other than rice) of Asian-Pacific region

A potential herbicide mix formulation to control a broad spectrum of weeds in cotton

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Cotton (*Gossypium hirsutum* L.) is one of the important *Kharif* crops in India and weeds pose a majorthreat to its cultivation. Weeds grow very rapidly in early stages of cotton crop and hence first 6 to 8 weeks after sowing is very critical. Poor weed control can result in about 50 to 85% loss in yield (Venugopalan *et al.* 2009). Different herbicides are applied sequentially and individually to control the total weed flora (broad leaves weeds and grassy weeds) in cotton crop. Alone application of different herbicides is inconvenient, difficult, cumbersome and more costly. Cotton selective herbicide pyrithiobac sodium controls major broad leaves weeds very effectively and grassy weeds partially. Therefore farmes seek for selective post emergence broad spectrum herbicide/ herbicide mixtures in order to achieve effective control of all weeds in a single spray. Pyrithiobac sodium and quizalofop ethyl are systemic herbicides with a specific target site of action and tank mixing or mix formulation of both the herbicides with 2 distinctly different target site of action has a potential for effective control of weeds in cotton. Keeping in view, the present study was undertakento evaluate a mixed micro emulsion concentrate (MEC 10%) herbicide formulation of pyrithiobac sodium and quizalofop ethylfor control of broad spectrum of weeds in cotton.

METHODOLOGY

Field experiments were carried out during *Kharif* season of 2012 and 2013 at experimental site of Research and Development Centre, Godrej Agrovet Ltd., Mumbai in randomized block design with four replications using cotton variety MRC-7326 Bt.Five herbicidal spray treatmentsviz. Pyrithiobac sodium 10% EC (62.5 g/ha), Quizalofop ethyl 5% EC (50 g/ha), MEC 10% (75 g/ha), MEC 10% (100 g/ha), MEC 10% (125 g/ha) were imposed on cotton at one week after sowing at 2-4 leaf stages of weeds. Observations on weed density and dry weight of weeds were recorded after 30 days of the sprays.

RESULTS

All the weed control treatments significantly reduced the weed numbers as compared to control. MEC 10% at 100 g/ ha and 125 g/ha were statistically at par and significantly superior over MEC 10% at 75 g/ha, Pyrithiobac sodium at 62.5 g/ha and quizalofop ethy at 50 g/ha (Table 1).

All the doses of MEC 10% resulted in significant reduction in total dry weight of weeds as compared to control. MEC at 100 and 125 g/ha were at par and significantly superior over Pyrithiobac sodium at 62.5 g/ha, quizalofop ethyl at 50 g/ ha and lower dose of MEC at 75 g/ha. Weed control efficiency was maximum in MEC at 125 g/ha followed by 100 g/ha (Table 1).

Table 1. Evaluation of herbicides mix formulation for control of broad spectrum of weeds in cotton

Treatment	Weed density (no./m^2)			Weed dry weight (g/m^2)	Weed control efficiency (%)
	Narrow leaf	Broad leaf	Total		
Pyrithiobac sodium 62.5 g/ha	10.2 (102.0)	6.1 (35.7)	16.2 (137.7)	5.04 (24.37)	39.8
Quizalofop ethy 50 g/ha)	6.6 (42.0)	9.6 (91.0)	16.1 (133.0)	5.80 (32.70)	19.2
MEC {Pyrithiobac sodium 6% + Quizalofopethyl4%} (75 g/ha)	7.4 (53.7)	7.2 (50.3)	14.6 (104.0)	4.40 (18.36)	54.6
MEC {Pyrithiobac sodium6%+ Quizalofopethyl 4%} (100 g/ha)	5.1 (24.7)	4.9 (24.0)	10.1 (48.7)	2.84 (7.10)	82.4
MEC {Pyrithiobacsodium 6% + Quizalofop ethyl 4%} (125 g/ha)	4.6 (20.3)	4.7 (20.7)	9.3 (41.0)	2.58 (5.66)	86.0
Control (Untreated)	10.1 (101.7)	9.5 (89.7)	19.7 (191.3)	6.44 (40.46)	-
LSD (P=0.05)	0.49	0.41	0.41	0.23	-

Figures in the parentheses are original. Data transformed to square root transformation "(X+1)

CONCLUSION

It was concluded that lowest weed density (41.0/m^2) and weed dry weight (5.66 g/m^2) and higher weed control efficiency (86.0%) were recorded in MEC at 125 g/ha followed by in MEC at 100 g/ha where weed density, weed dry weight and weed control efficiency recorded were 48.7/ m^2 , 7.10 g/m^2 and 82.4%, respectively. It is also revealed from the table that combination of Pyrithiobac sodium and Quizalofop ethyl as micro emulsion concentrate have a synergistic effect to control all weeds as compared to individual application of Pyrithiobac sodium 10% EC and Quizalofop ethyl 5% EC in cotton crop.

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Integrating herbicidal and conventional approach for profitable weed management in groundnut

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Groundnut (*Arachis hypogea* L.) is confronted by repeated flushes of diversified weed flora throughout its growing season. Competition of weeds cause substantial yield losses (Yadav *et al*. 2014) especially in bunch type groundnut varieties owing to its slow seedling emergence and initial growth, small foliage cover, prostrate growth habit and consequently poor competitive ability (Dayal 2004).

METHODOLOGY

To work out an effective weed management strategy based on herbicides alone or in combination with hand weeding, a field experiment was conducted during rainy seasons of 2009 and 2010 at PAU, Ludhiana in the Indo-Gangetic alluvial plains in the state of Punjab, northwestern India. The study comprised 7 treatments (Table 1) involving combinations of hand weeding(s) with pre-emergence application of pendimethalin (stomp 30 EC) 0.75 kg/ha, and post-emergence application of imazethapyr (Pursuit 10 WSC) 0.05 kg/ha allocated in randomized block design with three replications. Spanish bunch type groundnut variety *'SG 99'* was sown in the first fortnight of July with plant spacing of 30 x 15 cm fertilized with 15 kg N and 20 kg P_2O_5/ha applied as basal dose. The experiment was conducted with protective irrigation facility and other management practices were followed as per recommendations. Weed density and dry weight was recorded with the help of quadrate (0.25 m^2) placed randomly at two places at crop harvest. Species-wise weed seedlings within each quadrate was counted and the data on weed population was subjected to square root transformation prior to statistical analysis.

RESULTS AND DISCUSSION

The predominant weeds were *Digitaria sanguinalis*, *Cynodondactylon* (among grassy weeds - 9.3%), *Trianthema portulacastrum* and *Commelina benghalensis* (among broadleaf weeds- 26.3%) and *Cyperus rotundus* (sedge- 64.4%). Season long weed competition reduced the mean seed yield of groundnut by 60.9% in comparison to two hand weedings 3 and 6 WAS. Highest weed control efficiency (82.6%), the lowest weeds' dry weight (79.3 g/m^2) and highest pod yield of 2.13 t/ha was observed with two hand weedings done at 3 and 6 WAS (Table 1). Alone application of herbicides though provided moderate weed control (43.5-53.3% WCE) but the late flushes and regenerated weeds in later stages hampered the crop yield significantly. Synergism for weed management (72.3% WCE) and yield improvement (15.6-22.3%) was noticed with integrated approach in comparison to individual herbicide application either as pre- or post-emergence whatever the case may be. Integrated approach involving pendimethalin 0.75 kg/ha as PE + imazethapyr 0.05 kg/ha as PoE+ 1 hand weeding 45 DAS provided highest WCE (83.7 %), net returns (Rs 44.3 x 10^3/ha) with B:C ratio of 2.99 which was as good as implying two hand weedings 3 and 6 weeks after sowing (Table 1). Pre-emergence application of pendimathalin checked the grassy weeds by inhibiting their root and shoot growth, while post-emergence application of imazethapyr inhibited acetolactate synthase (ALS) oracetohydroxy acid synthase (AHAS) enzynatic activities causing destruction of mostly broadleaf weeds at 3-4 leafstage. Escapedor late emerging weeds were taken care by hand weeding done at 45 DAS, thereby providing weed free environment for longer period. This facilitated better peg initiation and development resulting in better expressions of yield attributing characters, *viz*. pods/plant, 100-kernel weight, shelling % age (data not shown) culminating in higher seed yield under integrated weed management strategy. Similar beneficial influence of integrated approach for better weed control and higher groundnut yield has also been reported by Yadav *et al.* (2014).

Table 1. Effect of weed management practices on weeds dynamics (density and dry weight), yield and economics in groundnut

Treatment	Weeds density (no./m^2)	Weeds dry wt. (g/m^2)	WCE (%)	Pod yield (t/ha)	Net returns (x10^3 Rs /ha)	B:C ratio
Unweeded control	136.7 (11.7)	456.2	-	0.83	8.7	1.49
Two hand weedings, 3 and 6 WAS	27.7 (5.4)	79.3	82.6	2.13	44.3	2.93
Pendimethalin 0.75 kg/ha	62.0 (7.9)	257.6	43.5	1.48	28.0	2.48
Imazethapyr 0.05 kg/ha, PoE 20 DAS	58.7 (7.7)	212.9	53.3	1.56	31.1	2.66
Pendimethalin 0.75 kg/ha, PE + Imazethapyr 0.05 kg/ha, PoE 20 DAS	40.7 (6.5)	126.6	72.3	1.81	37.6	2.90
Pendimethalin 0.75 kg/ha, PE + 1 HW 45 DAS	35.0 (6.0)	111.3	75.6	1.94	40.1	2.87
Pendimethalin 0.75 kg/ha, PE + Imazethapyr 0.05 kg/ha, PoE 20 DAS + 1 hand weeding 45 DAS	31.0 (5.7)	74.0	83.7	2.11	44.3	2.99
LSD (P=0.05)	16.2 (1.2)	49.4	-	0.16	-	-

Figures in parentheses indicate transformed values; HW: Hand weeding; WAS: Weeks after sowing; DAS: Days after sowing; PE-Pre-emergence: PoE: Post-emergence, WCE: Weed control efficiency

CONCLUSION

This study identifies pre-emergence application of pendimethalin 0.75 kg/ha followed by post-emergence application of imazethapyr 0.05 kg/ha 20 DAS + 1 hand weeding 45 DAS as the cost effective weed management strategy in groundnut considering the present situation of labour scarcity, quality of weed control, productivity and profitability concerns.

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Weed management options and strategies in pulse crops

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Historically, India is the largest producer, consumer and importer of pulses. Although India is the world's largest pulses producer, there is still a huge shortage of pulses to meet out the domestic demand of vegetarian population. Thus, there is an immediate need for the development and dissemination of low-cost technologies in pulses production, so that it can be affordable to the common man. Several biotic and abiotic constraints are responsible for poor productivity of pulses in the country. Weeds are the principal biotic constraints pulses production. An estimate shows loss of agricultural products due to weeds is more than the losses caused by other pests taken together. The yield losses due to weeds have been estimated to range from 30-50% in chickpea and up to 97% in pigeonpea. Manual weeding is generally being done but due to higher operational cost and also difficulties in carrying of the operation during rainy season, the option for use of herbicides was explored since long (Kumar *et al.* 2012). The effective weed control in pulses is essential to maximize seed yield and quality and to reduce weed competition in following crops. Till date, few herbicides are registered for the use in pulses and that too as pre-emergence or pre-plant application. Therefore, most of the recommendations in pulses are combination of pre-emergence herbicide and manual weeding. During last decade weed management research in pulses was focused on post-emergence herbicides. But very few post-emergence herbicides were found effective in managing diverse group of weeds in different pulses. Therefore, there is need to develop proper strategies for weed management in different pulse crops.

METHODOLOGY

Field studies were conducted during last three decades at Indian Institute of Pulses Research, Kanpur, India (26° 27′ N, 80° 14′ E and 152.4 m above MSL) to identify suitable weed management practices for pulse crops. The climate of this region is tropical sub-humid, receives annual rainfall of 722 mm and mean annual maximum and minimum temperature is 33 and 20°C, respectively. The field trials were conducted on different aspects of weed management in pulses during last 3 decades. During 1980s, trials were mainly conducted to see the effect of different weed groups on yield reduction and to identify critical period of crop-weed competition in different pulses. In 1990s, several trials were conducted on weed smothering efficiency of different pulses grown as intercrop. Pre-plant incorporation and pre-emergence herbicides were also used in studies along with manual weeding. During last one decade, research was focused to identify effective post-emergence herbicides and their doses in different pulses.

RESULTS

The studies revealed that initial 60-65 days are critical for weed management in pigeonpea, chickpea, lentil, rajmash and field pea, whereas initial 30-35 days are critical period in urdbean and mungbean. The yield loss due to weeds was observed up to 97% in pigeonpea, 87% in urdbean and 83% in lentil and chickpea. It was also observed that narrow leaved weeds and sedges affected pigeonpea yield to a greater extent than dicot weeds, whereas in chickpea, dicot weeds reduced chickpea yield more (53.3%) than the monocots (37.6%). Summer ploughing and sesamum in crop rotation were found effective in suppressing nutsedge in the subsequent crop. Nutsedge plants treated with glyphosate in stale bed recorded 54% nutsedge killing efficiency.Among different pulse intercrops, maximum weed smothering efficiency was observed in cowpea (45.8%) followed by urdbean (41.5%) and mungbean (38.2%). Among herbicides, pre-sowing incorporation of fluchloralin 0.5-1.0 kg/ha and oxadiazon 0.75 kg/ha were found most effective in controlling weeds in chickpea, lentil, mungbean, pigeonpea and urdbean. Pre-emergence application of pendimethalin 1.25-1.5 kg/ha was most effective in controlling broad leaved weeds in all the pulses. In frenchbean, pendimethalin 0.75–1.50 kg/ha or metachlor 0.50 – 1.0 kg/ha was found very effective. Studies on integrated weed management showed that effective weed control in different pulse crops can be achieved through pre-emergence application of pendimethalin 0.75-1.0 kg/ha + one hand weeding at 40-50 days after sowing. The phytotoxicity of pendimethalin 1.25 kg/ha applied as pre-emergence was observed in mustard under chickpea + mustard intercropping system.

Table 1. Major weed management recommendations in different pulse crops

Season	Crop	Recommendation
Kharif	Pigeonpea, mungbean and urdbean	• Pendimethalin 1.25 kg/ha (PE) + manual weeding at 35-40 DAS • Pendimethalin 1.25 kg/ha (PE) + Imazethapyr 100 g/ha at 15-25 DAS (POE)
Rabi	Chickpea, lentil and fieldpea	• Pendimethalin 1.25 kg/ha (PE) + manual weeding at 35-40 DAS • Pendimethalin 1.25 kg/ha (PE) + Quizalofop-ethyl 100 g/ha at 15-25 DAS (POE)
Summer	Mungbean/urdbean	• Manual weeding at 30-35 DAS • Imazethapyr 80 g/ha at 20-25 DAS (POE)

Out of the different post-emergence herbicides used under evaluation trials chlorimuron, metribuzin, metsulfuron methyl and metsulfuron methyl + chlorimuron has shown toxicity to almost all pulses grown during rainy as well as in winter season. Imazethapyr toxicity was observed in winter season pulses like chickpea, lentil and fieldpea. Results suggested that pendimethalin 1.25 kg/ha (PE) + quizalofop-ethyl 100-125 g/ha (POE) may be recommended for effective control of weeds in chickpea, lentil and field pea. Quizalofop-ethyl 100 g/ha was also found effective to contain rice ratoons growth which is a major problem in rice fallow-pulses. Similarly, pendimethalin 1.25 kg/ha (PE) + imazethapyr 100 g/ha (POE) was found effective in other rainy season pulses like pigeonpea and urdbean. However in summer mungbean, maximum yield was recorded in post-emergence application of imazethapyr 80 g/ha (1.01 t/ha) (Kumar *et al*. 2015).

CONCLUSION

The above studies suggested that even though few herbicides are available for use, integration of cultural and chemical (pre- and post-emergence herbicides) weed management methods can be used for effective weed control in pulse crops.

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Weed management in relay crop of blackgram

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In coastal districts of Andhra Pradesh, India cultivation of blackgram in rice fallows is a unique system of cultivation, wherein sprouted seeds of blackgram are directly broadcasted in the standing rice crop 2-3 days prior its harvest. Thus the blackgram sown in this system survives entirely on residual moisture and fertility. Among the different constraints, weed menace receives special attention as it can reduce the crop yield ranging from 31-75% depending on the severity of weed infestation (Rao 2008). Lack of field preparation, lack of optimum plant population per unit area, excessive moisture in early stage, already established weeds at the time of paddy harvest are some of the reasons for severity of weed problem. More than 25 weeds were found to infest rice fallow blackgram and among them are *Echinochloa colona, Leptochloa chinensis (*grasses*), Cyperus rotundus, C. kyllinga (*sedges*), Chrozophora rottleri, Cardanthera uliginosa, Cleome chelidoni, Grangea maderaspatana, Vicia satvia* (broad leaved weeds). *Cuscuta chinensis* (parasitic weed) is the most problematic weed and critical period of crop weed competition is upto 30-days after sowing.

Weed management in rice fallow blackgram either by physical or mechanical and chemical methods is very difficult compared to that in upland blackgram. Hand weeding is difficult to practice because of presence of rice stubbles in addition to the problem of trampling of blackgram seedlings as seeds are broadcasted in the soil surface. Intercultivation is also not possible as the seeds are broadcasted. Therefore, chemical control of weeds is the only option. Again in chemical control also normal pre-emergence application of herbicides is also not possible as the crop already germinated/ established and presence of left over weeds of paddy crop by the time of removal of paddy sheaves. Keeping all these in view, serious efforts were made by the weed control unit, Lam, Guntur, Andhra Pradesh during the last two decades and results of research indicated that application of butachlor 2.0 kg/ha or pendimethalin 1.0 kg/ha by mixing with 50 kg sand/ha and apply immediately after removal of paddy sheaves preferably in the evening times and water spray at 500 l/ha should be followed immediately in order to create normal pre-emergence situation as the crop already germinated. This will control some of annual grasses and broad leaf weeds only but not *Vicia sativa* and late emerged weeds like *Grangea maderaspetana*, *Chrozophora rottleri*. But this method is found be cumbersome as the farmers are busy with heaping of paddy sheaves and availability of labour for water spraying is problem. Further, for the control of grassy weeds, post emergence application (at 20-25 DAS) of fenoxaprop ethyl 56 g/ha, clodinafoppropargy l53 g/ha, quizalofop ethyl 50 g/ha, propaquizafop ethyl 63 g/ha, cyhalofop butyl 100 g/ha *etc.* were found to be effective (Appanna *et al.* 1998, Rao 2008). For control of grasses and broad leaf weeds post emergence application of imazethapyr 50 g/ha either alone or in sequence with sand mix application of pre emergence herbicides was found to be effective though it causes slight injury, but crop will be recovered in a week or so (Rao *et al.* 2010). This will also control to some extent *Cuscuta* but not legume weed *Vicia sativa* which is a serious problem in north coastal districts. Recently preliminarily trails conducted on control of *Vicia sativa* indicated that post emergence application (25-30 DAS) of ready mix of acifluorfen+ clodinafop propargyl found to be very effective along with grasses and broad leaf weeds but was found to be ineffective against another problematic weed *Cuscuta*.

Cultivation of rice fallow blackgram is a unique system of cultivation wherein hand weeding, intercultivation and normal methods of pre emergence herbicides is not possible. As the farmers have only option of using selective post emergence herbicide, therefore efforts should be made to develop a broad spectrum herbicide or herbicide mixture which control all groups of weeds in a single spray.

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Weed management in rainfed agriculture in India: Issues and future strategies

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Weeds indirectly cause abiotic stress by exhausting the limited soil moisture and nutrients. Effective and economical weed control recommendations, including cultural, mechanical and chemical, have been developedfor rain fed crops. Recently, the research focus is mainly on developing low cost weeder and interaction of tillage and weed management, particularly in the context of conservation agriculture.

STATUS OF WEED MANAGEMENT

In spite of the fact that crop yields can almost be doubled through proper weed management during critical stages of crop growth, majority of dry land farmers have showed relatively little interest on adoption of improved weed management practices, due to

Weeds occur as constant companion of the agricultural crops and many farmers fail to recognize the adverse effects of weeds on crops.

Livestock is an integral component of rain fed farming systems and often weeds are allowed to grow along with crops to use as green fodder.

Lack of awareness on herbicides and poor affordability and non-availability of suitable herbicides considering the diverse cropping systems practiced by rain fed farmers.

Though many implements have been developed for weeding in rain fed crops, due to the prevalence of inter- and mixed-cropping their use has not become popular over large areas.

ISSUES IN WEED MANAGEMENT

Weeds require just as much, and often more, water than crops and are often more successful in acquiring it. In rain fed areas, a very narrow sowing window is available and many times it may not be possible to apply pre-emergence herbicides immediately after sowing. Cropping systems are highly diversified and location-specific. Inter- and mixed-cropping are common in rain fed areas. This makes it difficult to use intercultural implements or herbicides for weed control. It is necessary to develop implements for performing several operations such as seeding, formation of ridges and furrows, and herbicide application in a single pass. Another approach is to develop and identify suitable post-emergence herbicides for different cropping systems. Rainfed areas are highly diverse in terms of soils, rainfall pattern, socio-economic conditions of farmers *etc*. necessitating need for development of location-specific weed management technologies for different crops.

Efficient conservation of resources including soil and rainwater through conservation agriculture is gaining importance in rain fed areas. Losses in crop yields as a result of increased weed densities have been cited as major reasons why conservation tillage systems have not enjoyed widespread adoption. Hence, development of integrated weed management modules could help in wider adoption of conservation agriculture practices in rain fed areas. Similarly, the vast majority of rainfed farmers in remote areas still practice low external input or no external input farming which is well integrated with livestock, particularly small ruminants. Thus, rain fed areas and regions in north east India have been identified as more suitable for organic farming in view of the low input use. There is need for research on organically approved non-chemical integrated weed management methods for different cropping systems. Rain fed agriculture is likely to be more vulnerable in view of its high dependency on monsoon and the likelihood of increased extreme weather events due to aberrant behavior of south-west monsoon. Several factors including weed abundance, efficacy of herbicides under extreme weather events, influence of soil moisture on performance of mechanical and cultural methods of weed control etc. will come into play in either enhancing or constraining the current capacity of rain fed farmers to cope with climate change.

CONCLUSION

Integrated weed management continues to be as relevant to rain fed agriculture, the main challenge lies in developing herbicides and weeders/implements, which could address the location specific needs of the rain fed areas with diverse soil types, topography, rainfall pattern and cropping systems.

Weed flora and yield of winter maize + potato intercropping system as influenced by weed management

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Maize (*Zea mays* L.) being native of Mexico is one of the oldest and most productive cereal food crop. The acreage of winter maize (*Zea mays* L.) in India is increasing very fast due to its higher productivity and net profit compared to traditional *Kharif* crop. The average productivity of winter maize is 4.0 t/ha compared to 2.0 t/ha of *Kharif* maize (Anonymous 2007). Maize being a widely spaced crop gets infested with variety of weeds and subjected to heavy weed competition. Intercrops may demonstrate weed control advantages over sole crops in two ways. Potato is considered to be most remunerative crop in space and time. Planting potato as intercrop in between main rows not only helps in the maximum utilization of natural resources but also contributes higher yield of crops. Therefore, an investigation was carried out to study the effect of different weed management practices on weed control and yield of winter maize + potato intercropping system under agro climatic conditions of Jammu.

METHODOLOGY

A field experiment was conducted on sandy loam soil during the *Rabi* 2009-10 and 2010-11. The experiment consisted of four main plot treatments; winter maize (sole), potato (sole), winter maize + potato (additive series) and winter maize + potato (replacement series) and six sub-plot treatments comprising of weedy check, weed free, alachlor pre-emergence at 1.5 kg/ha, atrazine pre-emergence at 0.5 kg/ ha, early post-emergence alachlor at 2.0 kg/ha and atrazine post-emergence at 0.75 kg/ha and laid out in split plot design with three replications. Winter maize '*Bulland*' of 175 days duration and potato '*Kufri Sinduri*' of 120 days duration were sown at row spacing of 60 cm. Application of fertilizer in sole maize was 175-60-30 kg NPK /ha, whereas in case of sole potato was 120-60-120 kg NPK /ha.

RESULTS

Broad leaved weeds were predominant (51.2%) followed by sedges (36.7%) and grassy weeds (12.1%). *Medicago sativa* among the broadleaved weeds, *Phalaris minor* among the grassy weeds and *Cyperus rotundus* among the sedge were more dominant. Herbicidal treatments significantly influenced the population and dry matter production of weeds. It was observed that sole winter maize resulted in higher weed density (8.4/m^2) which was significantly higher than sole potato and winter maize + potato in replacement series (8.2 /m^2), whereas the lowest total weed density (7.2 / m^2) was recorded in winter maize + potato (additive series). This might be due to the fact that slow initial growth and wider row spacing of maize provided relatively conducive conditions for growth of weeds (Pandey *et al.* 2003). Among weed management practices, lowest total weed density (6.6/ m^2) and weed biomass (6.1 g/m^2) were recorded with application of atrazine pre-emergence at 0.5 kg/ha which was followed by post-emergence application of atrazine at 0.75 kg/ ha. Winter maize + potato (additive series) appeared to be biologically most efficient system giving the highest production efficiency (88.87 kg/ha/day) followed by winter maize + potato (replacement series). Intercropping of winter maize+potato (additive series) significantly enhanced kernel yield (3.6 t/ha) of winter maize. Among the weed management practices, pre-emergence application of atrazine at 0.5 kg/ha recorded significantly higher grain yield which was statistically at par with post-emergence application of atrazine at 0.75 kg/ha and pre-emergence application of alachlor at 1.5 kg/ha.

Table 1. Weed density, weed dry weight, production efficiency and yield of maize and potato as influenced by different weed control treatments in winter maize-potato intercropping system

Treatment	Weed density/m^2 90 DAS	Weed dry weight (g/m^2) 90 DAS	Production efficiency kg/ha/day	Maize (t /ha)	Potato (t/ha)
Intercropping systems					
Sole maize	8.4(90.6)	8.0 (73.6)	26.4	4.8	-
Sole potato	7.7(75.8)	7.4 (67.7)	84.9	-	23.7
Winter maize + potato (Additive series)	7.2(66.8)	6.9 (60.0)	88.8	3.6	19.2
Winter maize + potato (Replacement series)	8.2(88.0)	8.2 (80.3)	65.0	2.3	14.5
CD(p=0.05)	0.14	0.13		0.14	0.9
Weed management (WM)					
Weedy check	15.5(241.0)	14.8 (208.5)	40.3	1.75	12.3
Weed free	1.0(0.00)	1.0 (0.00)	76.4	4.4	21.5
Alachlor pre-emergence at 1.5 kg/ha	7.5(57.3)	7.3 (50.5)	72.2	3.8	20.9
Alachlor pre-emergence at 2.0 kg/ha	9.2(84.0)	9.2 (80.5)	68.3	3.4	20.1
Atrazine pre-emergence at 0.5 kg/ha	6.6(42.4)	6.1 (33.9)	72.0	4.0	20.5
Atrazine post-emergence at 0.75 kg/ha	7.5(57.0)	7.3 (50.4)	68.5	3.9	19.4
LSD (P= 0.05)	0.08	0.09	NA	0.13	0.7

*Figures in parenthesis are original values subject to "x+1 square root transformations, DAS : Days after sowing, NA : Not analyzed

CONCLUSION

It was concluded that winter maize + potato (additive series) and pre-emergence application of atrazine at 0.5 kg/ha were most effective for controlling weeds and improving grain yield of maize and tuber yield of potato.

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Integrated weed management in spring sugarcane

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Adoption of improved technology based on seed nutrient and plant protection has enabled the attainment of self-sufficiency of food in India. However, there is a fear that it may hort-lived, as a gap between food demand and supply is increasing due to high population growth rate. In this situation, the urgency lies in increasing agricultural productivity with technologies that lead to remunerative, sustainable and eco-friendly agricultural system.

Sugarcane is the most important cash crop of Maharashtra. Sugar industry plays a pivotal role in the socio-economic and educational development in rural areas of Maharashtra. During 2013-14, the area of sugarcane in the state was 10.54 lakh hectares with 767.0 lakh tons of Sugarcane production. The average sugarcane productivity was 82.5 t/ha while the average sugar recovery of 11.41% attained 11.41%. Many production factors are responsible for poor productivity of sugarcane, *viz.* pure seed, nutrient and water management, aftercare operations in which weed management in a crucial one. Weeds are among the most under estimated pest, especially in India, where they cause average crop losses of 33 percent and more. Low productivity is mainly due to heavy weed infestation (Srivastava *et al.* 2002). It is more appropriate that weeds, unlike insect and diseases often cause hidden symptoms of damage prior to harvest of sugarcane, and possibly also because of fatalistic attitude that weeds will always be present. Labour shortage is always there with sugarcane production. Therefore, the investigation was planned with objective to find out economical and effective weed management system in spring sugarcane

METHODOLOGY

The field experiment was conducted to assess the performance of different weed management practices in spring sugarcane variety '*Co 86032*' during year 2008-09 to 2010-11 at Central Sugarcane Research Station, Padegaon. The twelve treatments (Table 1) were replicated thrice in randomised block design. The sugarcane variety '*Co 86032*' was planted in spring season with 120 cm row spacing in gross and net plot size 10 x 7.20 m and 8 x 4.80 m, respectively. The crop was fertilized with 300:140:140 kg/ha N, P_2O_5 and K_2 O. The soil of experimental plot was medium black.

RESULTS

The major weed flora observed in experimental plot were, *viz. Cynodon dactylon, Panicum isachne, Commelina benghalensis, Bracheria* spp (among grasses); and, *viz. Parthenium hysterophorus, Portulaca olerecea, Convolvulus arvensis, Ameranthus viridis, Digeria arvensis, Ipomoea aquatica, Eclipta* spp.*, Xanthium strumarium and Euphorbia* spp. (broad leaf weeds) and *Cyperus rotundus* (sedge).

Application of atrazine at 2 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 15-18 DAP + hoeing at 90 DAP (T_{10}) significantly reduced the weed intensity which was found at par with metribuzine at 1.0 kg/ha as PoE at 15-18 DAP + power tiller with rotator at 90 DAP (T_{12}), atrazine at 2.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 15-18 DAP+ atrazine at 2 kg/ha + 2,4-D at 1.0 kg/ha as PoE at 45 DAP (T_{11}), metribuzine at 1.0 kg/ha spray at 15-18 DAP + metribuzine at 1 kg/ha as PoE at 45

Table 1. Weed dynamics, sugarcanegrowth, yield and economics as affected by various weed

Treatment	Weed intensity (no. /m^2)			Weed dry wt. (g/m^2)		WCE (%)	Millable canes /ha	Cane yield (t/ha)	CCS yield (t/ha)	Net profit (₹/ha)	B:C ratio
	30 DAP	60 DAP	90 DAP	60 DAP	90 DAP	90 DAP					
Weedy check	35.0 (6.00)	46.0 (6.84)	59.00 (7.74)	59.0 (7.72)	64.0 (8.05)	--	84503	72.01	9.85	10225	1.14
Two weeding at 30 and 60 DAP + 1 hoeing at 90 DAP.	33.0 (5.82)	21.0 (4.68)	18.00 (4.34)	23.0 (4.81)	17.0 (4.22)	70.3	93866	108.01	14.82	41801	1.52
Atrazine at 2.0 kg/ha as PE +2,4-D at 1.0 kg/ha as PoE at 60 DAP + hoeing at 90 DAP	17.0 (4.24)	30.0 (5.56)	18.00 (4.33)	34.0 (5.88)	20.0 (4.56)	68.7	95928	111.80	15.53	50416	1.66
Metribuzine at 1.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 60 DAP + hoeing at 90 DAP	11.0 (3.45)	19.0 (4.46)	14.00 (3.85)	23.0 (4.83)	18.0 (4.35)	71.8	98093	115.52	17.33	54628	1.72
Metribuzine at 1.0 kg/ha as as PoE spray at 15-18 DAP + hoeing at 90 DAP.	8.00 (3.00)	16.0 (4.12)	27.00 (5.26)	19.0 (4.44)	33.0 (5.71)	48.4	96056	107.96	15.01	46162	1.60
Atrazine at 2.0 kg/ha as PE + Atrazine at 2.0 kg/ha as PoE at 45 DAP.	17.0 (4.24)	17.0 (4.23)	29.00 (5.45)	18.0 (4.11)	29.0 (5.40)	54.6	94205	101.72	13.94	39608	1.52
Metribuzine at 1.0 kg/ha spray at 15-18 DAP + metribuzine at 1.0 kg/ha as PoE at 45 DAP	8.0 (3.00)	6.00 (2.62)	21.00 (4.64)	9.00 (3.06)	21.0 (4.66)	67.1	95910	103.68	14.37	39832	1.51
Atrazine at 2.0 kg/ha as PE + Tractor drown cultivator at 60 DAP.	17.0 (4.24)	32.0 (5.73)	13.00 (3.73)	35.0 (5.96)	17.0 (4.22)	73.4	94600	100.63	13.64	38210	1.50
Atrazine at 2.0 kg/ha as PE + Tractor drown cultivator at 90 DAP.	18.0 (4.35)	31.0 (5.66)	34.00 (5.89)	35.0 (5.96)	41.0 (6.44)	35.9	94168	97.86	13.57	35014	1.46
Atrazine at 2.0 kg/ha as PE +2,4-D at 1.0 kg/ha as PoE at 15-18 DAP + hoeing at 90 DAP.	6.00 (2.64)	22.00 (4.76)	27.00 (5.27)	29.0 (5.44)	32.0 (5.71)	50.0	95585	104.85	14.46	43642	1.58
Atrazine at 2.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 15-18 DAP. + Atrazine at 2.0 kg/ha,+2,4-D at 1.0 kg/ha as PoE at 45 DAP.	8.00 (3.00)	14.0 (3.86)	24.00 (4.96)	17.0 (4.21)	25.0 (5.07)	60.9	95989	105.02	14.45	41958	1.54
Metribuzine at 1.0 kg/ha as PoE at 15-18 DAP + power tiller with rotator at 90 DAP.	8.00 (2.99)	18.0 (4.33)	29.00 (5.46)	20.0 (4.48)	32.0 (5.65)	50.0	96272	106.66	14.64	45123	1.59
LSD (P=0.05)	0.54	0.90	1.21	1.98	1.64		1.15	4.07	0.95		

DAP (T_7) and metribuzine at 1 kg/ha as as PoE spray at 15-18 DAP + hoeing at 90 DAP (T_5). The dry weight of weeds at 30 DAP was significantly lower in application of atrazine at 2.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 15-18 DAP + atrazine at 2.0 kg/ha + 2,4-D at 1.0 kg/ha as PoE at 45 DAP (T_{11}) which was found at par with $T_{12,}$ $T_{10,}T_{7,}$ T_5 and T_4 (Table 1).

Application of metribuzine at 1.0 kg/ha as PE spray+ 2,4-D at 1.0 kg/ha as PoE at 60 DAP + hoeing at 90 DAP observed significantly higher millable canes (98093 /ha) and cane yield (115.5 t/ha) and CCS yield (17.2 t/ha) than other treatments. While the cane yield was found at par with application of atrazine at 2.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 60 DAP +hoeing at 90 DAP (111.8 t/ha). Metribuzine at 1.0 kg/ha as PE +2,4-D 1.0 kg/ha as PoE at 60 DAP + hoeing at 90 DAP realized the higher net profit (₹ 54628/ha) and B:C ratio (1.72) followed by Atrazine at 2.0 kg/ha as PE + 2,4-D at 1.0 kg/ha as PoE at 60 DAP +hoeing at 90 DAP.

CONCLUSION

In spring planted sugarcane, application of metribuzine 1.0 kg/ha as PE + 2,4-D 1.0 kg/ha spray at 60 DAP + hoeing at 90 DAP found superior for control of weeds in sugarcane with the highest weed control efficiency (80.8) at 120 DAP and also recorded significantly highest cane and CCS yield (115.52 and 17.33 t/ha respectively), net profit (54628/ha) and benefit cost ratio (1.72). Application of atrazine at 2.0 kg/ha as PE + 2,4-D 1.0 kg/ha as PoE at 60 DAP + hoeing at 90 DAP was found the next best treatment for weed control in sugarcane.

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Weeds and weed control in finger millet in India – A review

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Eleusine coracana (L.) Gaertn is a nutritious and under exploited minor millet with several edible and industrial uses.Finger millet is cultivated on 1.176 million ha, with average yields of 1.64 t/ha, in India (DMD, 2014). The major finger millet growing (with area more than 10,000 ha) states of India are: Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Orissa, Andhra Pradesh, Gujarat, Jharkhand, West Bengal, Bihar and Chattisgarh. About 13.3% and 20.6% of the total area and production of finger millet is contributed by irrigated ecosystem in India. Finger millet is cultivated, mainly as rainfed crop, by seeding (broadcast- or row-seeding) and transplanting methods of establishment in India. Weeds are the major constraints limiting the productivity of finger millet due to initial slow growth of the small seeded finger millet which favors weed growth resulting in severe competition for limited resources. The objective of this review is to list weeds associated with finger millet in different parts of India and summarize the weed management options for effectively managing weeds in finger millet.

METHODOLOGY

The literature published in national and international journals on "Weeds and weed management in finger millet in India" was collected. All the papers published were read, analyzed and summarized as a review in this paper.

RESULTS

Of 88 weed species reported to be associated with finger millet in India, the most commonly reported weeds (in decreased order of importance) include: *Cyperus rotundus*, *Cynodon dactylon*, *Commelina benghalensis*, *Ageratum conyzoides*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Digitaria marginata*, *Eleusine indica*, *Spilanthes acmella*, *Acanthospermum hispidum*, *Eragrostis pilosa*, *Parthenium hysterophorus*, *Amaranthus viridis*, *Celosia argentea*, *Alternanthera sessilis*, *Dinebra retroflexa*, *Digitaria sanguinalis*, *Euphorbia hirta* and *Ocimum canum*. The pre-dominant weed flora varied in different states of India. If un-weeded, weeds smother the finger millet resulting in significant reduction in the yield by 5-70% owing to weed competition. Critical period for weed competition was identified to be first 4-6 weeks from planting in irrigated transplanted finger millet and first 5 weeks under rainfed conditions, respectivelyand thus should be kept weed free to prevent losses in yield.

Traditionally, direct row-seeded finger millet is often cultivated, twice or thrice at ten-day intervals, by farmers with tined implements drawn by draft animals. In regions where animal or machine power is not available, the weeding and cultivation operations are usually carried out by hand. Pre - emergence application of bensulfuron methyl + pretilachlor, butachlor, isoproturon, metoxuron, neburon, nitrofen, oxadiazon, oxyfluorfen and post - emergence application of 2,4-D, chlorimuron ethyl, MSMA and propanil, were found to be effective in managing weeds either alone or in combination with hand weeding or inter cultivation. Non-chemical method like stale seedbed with inter cultivations was also found to be effective in managing weeds. Integrated weed management was found to be more economical in managing weeds in finger millet.

CONCLUSION

For improving finger millet productivity, it is important to manage weeds during the critical period of crop weed competition and create conducive environment for crop. Integrated weed management strategies that are effective, economical and environment friendly are to be designed, tested and popularized among farming community to manage weeds and improve productivity and production of finger millet in India.

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Efficacy of new herbicide molecules in rainy-season grain sorghum

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Sorghum [*Sorghum bicolor* (L.) Moench] is an important staple cereal crop of semi-arid tropical regions of India. Weeds are a major deterrent in increasing the sorghum productivity, especially during rainy season. Grain sorghum seedlings are comparatively small and grow slowly for the first 20-25 days and consequently do not compete well with most weeds in the early stage of crop growth, resulting in a yield loss of 15-83% (Mishra *et al*. 2012). Atrazine as pre-emergence is the most widely used herbicide for weed control in sorghum. However, lack of soil moisture may decrease the efficacy of pre-emergence herbicides. Hence, the present investigation was undertaken to evaluate the efficacy of new herbicide molecules in grain sorghum.

METHODOLOGY

A field experiment was conducted during *Kharif* season of 2014 at the Directorate of Sorghum Research, Hyderabad consisting of nine treatments (Table 1) in a randomized block design with three replications. Two more herbicides, *viz*. imazethapyr at 100 g/ha and imazethapyr + imazamox ready mix at 70 g/ha, each applied at 15 DAS were also evaluated, but as these molecules resulted into complete mortality of sorghum within a week after application, no data could be recorded, and hence, not included in the Table. The sorghum '*CSH 16*' was sown in rows at 45 x 15 cm on 8 July 2014. Herbicides, as per treatments, were applied in 500 l/ha spray volume with knapsack sprayer fitted with flat-fan nozzle. Pre-emergence herbicides were applied next day after sowing. Weed count, for estimating weed density and total weed dry weight were recorded at crop maturity with the help of a quadrate (0.50 x 0.50 m) placed randomly at four spots in each plot. The data on weed dry weight were subjected to square root transformation ("x+0.50) before statistical analysis.

RESULTS

The relative density of broad-leaved weeds was higher (65.9%) compared to grasses (27.1%) and sedges (7%). The dominant broadleaf weeds were *Commelina benghalensis*, *Trianthema portulacastrum*, *Tridax procumbens*, *Trichodesma indicum*, and *Parthenium hysterophorus*; grass weed species comprised of *Echinochloa colona, Eleusine indica, Dinebra retroflexa, Digitaria sanguinalis* and *Dactyloctenium aegyptium*; and sedges such as *Cyperus iria*. Application of herbicides except penoxsulam at 15 DAS significantly reduced the weed dry weight at harvest as compared to weedy check (Table 1). Tank mix application of atrazine + pendimethalin (500 + 750 g/ha) as pre-emergence was most effective in controlling weeds and increasing sorghum grain yield (5.87 t/ha). Atrazine as post-emergence (4.46 t/ha) was less effective as compared to pre-emergence (5.81 t/ha). New herbicide molecules, *viz*. penoxsulam, pendimethalin + imazethapyr and imazethapyr + imazamox ready mix were very effective in controlling weeds and safe to sorghum crop, but produced lower grain yield due to reduction in number of grains/panicle. This needs further investigation.

Table 1. Effect herbicides on growth, yield attributes, yield and weed dry weight of grain sorghum

Treatment	Dose (g/ha)	Time of application	LAI at 60 DAS	Plant height (cm) at harvest	Number of panicles/ m^2	Panicle length (cm)	Grains/ panicle	100 - grain weight (g)	Grain yield (t/ha)	Dry fodder yield (t/ha)	Weed dry weight (g/m^2) at harvest *	WCE (%)
Atrazine	500	1 DAS	4.72	205	13.93	32.00	1146	3.64	5.81	12.89	6.47 (47)	78.34
Atrazine + pendimethalin (tank mix)	500 +750	1 DAS	5.12	204	12.03	31.33	1595	3.09	5.87	13.33	4.93 (33)	84.79
Pendimethalin + imazethapyr (tank mix)	750 + 100	1 DAS	5.20	197	12.83	31.40	1120	3.43	3.72	11.55	10.86 (124)	42.86
Penoxsulam	25	15 DAS	3.53	207	13.49	31.47	1152	3.63	4.01	10.22	14.34 (207)	4.6
Atrazine	500	15 DAS	3.93	209	12.47	30.27	1012	3.53	4.46	11.55	11.2 (125)	42.4
Penoxsulam	25	1 DAS	4.60	203	13.40	31.90	888	3.07	4.15	8.09	4.13 (17)	92.16
Pendimethalin+ imazethapyr ready mix	750 + 50	1 DAS	4.60	200	13.11	33.73	959	3.26	4.72	8.67	2.3 (7)	96.77
imazethpyr + imazamox ready mix	70	1 DAS	4.37	209	14.52	32.60	631	3.39	3.10	10.67	5.94 (36)	83.41
Weedy check			3.01	209	12.17	31.53	970	3.58	4.70	9.78	14.59 (217)	0
LSD (P=0.05)			0.79	11	1.06	2.58	398	0.50	1.56	3.92	4.17	

*Values in parentheses are original. Mention the type of transformation followed for analyzing the weed data.

CONCLUSION

It may be concluded that tank mix application of atrazine + pendimethalin (500 + 750 g/ha) as pre-emergence was safe and most effective in sorghum. New herbicide molecules *viz*., penoxsulam, pendimethalin + imazethapyr and imazethapyr + imazamox ready mix, though effectively controlled the weeds but reduced the grain yield due to reduction in number of grains/panicle.

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Energy usage and benefit-cost analysis of cotton under various weed management practices

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The introduction of modern inputs changed the energy scenario of crop production. The main problems facing energy usage are insufficient resources, high production costs, wrong resource allocation and increasing national and international competition in agricultural trade. Agricultural energy requirements can be divided into direct and indirect energy requirements. The direct energy is related to crop production process as land preparation, irrigation, inter-culture, threshing, harvesting and transportation of agricultural inputs and farm produce. Indirect energy needs are in the form of crop production inputs like seed, fertilizer and plant protection chemicals including bio-control agents. Efficient use of these energies helps to achieve increased production and productivity and contributes to economy, profitability and competitiveness of agricultural sustainability to rural livelihoods. The output energy is obtained in the form of feed, fodder, fruits, vegetables, seed and grain. Developing countries have lagged behind industrialized countries in modernizing their energy inputs to agriculture. Agricultural practices in many developing countries continue to be based to a large extent on animal and human energy. Mechanical and electrical energy are available for agriculture insufficiently and hence the potential gains in agricultural productivity through the deployment of modern energy services are not being realized.

METHODOLOGY

The following different energy efficiency parameters were determined to evaluate relationship between energy consumption and total output and production per hectre. Energy ratio, specific energy, energy productivity, energy intensiveness and net energy yield were calculated using the following Energy ratio = Energy output (MJ/ha)/Energy input (MJ/ha); Specific energy = Energy input (MJ/ ha)/Output (kg/ ha); Energy productivity = Output (kg/ha)/Energy input (MJ/ ha); Energy intensiveness = Energy input (MJ/ha)/Cost of production (Rs/ha) and Net energy yield = Energy output (MJ/ha) – Energy input (MJ/ha). This calculations were carried out based on experimental results of cotton, conducted at college farm, Professor Jayashankar Telangana State Agricultural University, Rajendranagar during *Kharif* 2014 with 10 weed management practices replicated thrice.

RESULTS

In this study, total energy consumption of cotton production under various weed management practice varied in between 16051 MJ/ha to 19575 MJ/ha. Energy output-input ratio shows the efficiency of energy input and also marginal increase of output due to per unit increase in energy input. This ratio is generally higher in lower energy input and lower in higher energy input. Energy efficiency is an useful physical measurement. Among various weed management practices mechanical weeding thrice showed high energy ratio, low specific energy with higher productivity and this was followed by pre-emergence application of pendimethalin at 1000 g/ha *fb* hand weeding twice at 20 and 40 DAS. Net energy yield was found to be negative for all the treatments.

Table 1. Energy input-output relationship for cotton production under various weed management practices

Treatment	Kapas yield kg /ha	CC `/ha	Energy out put (MJ/ha)	Total energy input (MJ/ha)	Energy ratio	Specific energy	Energy productivity	Energy intensiveness	Net energy yield
Pendimethalin *fb* 2 HW	1209	32840	14266	17718	0.8	14.6	0.06	0.5	-3452
Pendimethalin *fb* pyrithiobac-sodium	535	27127	6313	17905	0.3	33.4	0.02	0.7	-11592
Pendimethalin *fb* pyrithiobac-sodium + quizalofop- p - ethyl	637	27449	7516	18193	0.4	28.5	0.03	0.7	-10677
Pyrithiobac-sodium + quizalofop- p -ethyl	583	25858	6879	17243	0.4	29.5	0.03	0.7	-10364
Pyrithiobac-sodium + quizalofop- p- ethyl *fb* manual weeding	1019	29608	12024	17046	0.7	16.7	0.05	0.6	-5022
Pyrithiobac -sodium + quizalofop –p- ethyl *fb* directed spray of paraquat	783	26758	9239	17963	0.5	22.9	0.04	0.7	-8724
Pyrithiobac-sodium + quizalofop –p- ethyl *fb* directed spray of glyphosate	806	27809	9510	18625	0.5	23.1	0.04	0.7	-9115
Pendimethalin *fb* glyphosate directed spray	828	27291	9770	19575	0.5	23.6	0.04	0.7	-9805
Mechanical weeding (3)	1427	26750	16838	18550	0.9	12.9	0.07	0.7	-1712
Weedy check	200	23750	2360	16051	0.1	80	0.01	0.7	-13691
LSD (P=0.05)	231.34								

CONCLUSION

Based on the analysis there is a need to increase the cotton output to get more net energy yield in order to increase the energy use efficiency of inputs.

Bio-efficacy of post emergence tembotrione on weed dynamics and productivity of *Kharif* maize in rainfed foothill and mid hill conditions

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Maize (*Zea mays* L.) called as "Queen of cereals" is one of the most important crop in the world's agricultural economy. The crop is cultivated on an area of about 159.2 mha globally with production and productivity of 835 mt and 5.24 t/ ha, respectively (Anonymous 2012) . It is a versatile crop and has a great potential to grow in the foot-hill and mid-hill conditions in the state. In the state of Jammu and Kashmir maize has special significance because it forms the staple diet of majority of the people living in the state. It is a popular crop of rainfed areas of Jammu region, which constitutes about 70% area. Maize being wide spaced crop and its slow growth during initial period favours weed growth even before the crop emergence. Yield losses due to season long weed infestation range from 30% to complete crop failure Usage of pre-emergence herbicides assumes greater importance in the view of their effectiveness from initial stages. But there is no post emergence herbicides still available in market. Unfortunately if farmer miss the application of pre emergence herbicides due to scarcity of labour or unfavourable weather conditions, then there is no alternative for him to control the weeds emerging in later stages except resorting to amnual weeding. Tembotrione, a new post emergence broad spectrum systemic herbicide belonging to group Triketone, is a pigment synthesis inhibitor, inhibits 4-HPPD enzyme, control broadleaved as well as grassy weeds. Thus, managing weeds through pre-emergence and post emergence herbicides will be an ideal means for controlling the weeds in view of their economics and effectiveness in maize. Hence, keeping the above facts in the fore front, a study was carried out to find out the efficacy of post emergence herbicides as an alternative to manage weeds during later stages.

METHODOLOGY

A field experiment was carried out during the *Khari*f season of 2013 at the Research Farms of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu to evaluate the effect of post emergence tembotrione application on weed dynamics and productivity of *Kharif* maize in rainfed foothill and mid hill conditions of Jammu & Kashmir. The experiment was laid out in randomized block design comprising eleven treatments with three replications. The treatments consisted of tembotrione at 110 g/ha at 15 DAS, tembotrione at 110 g/ha at 30 DAS, tembotrione at 120 g/ ha at 15 DAS, tembotrione at 120 g/ha at 30 DAS, tembotrione at 31 g/ha + atrazine at 370 g/ha at 15 DAS, atrazine at 1 kg/ha at —— DAS , pendimethalin at 1 kg/ha, halosulfuron methyl at 135 g/ha at 15 DAS, 2 hand weedings at 15 DAS and 30 DAS, weedy check and weed free. Maize crop variety '*Double dekalb*' was sown with a seed rate of 20 kg/ha. The mean data on weeds were subjected to square root transformation ("x+1) to normalize their distribution.

RESULTS

The experimental field was infested with mixed weed flora. Grassy weeds were predominant (52%), followed by sedges (32%) and broad-leaved (16%). E*chinochloa colona* among the grassy weeds and *Cyperus rotundus* among the sedges were more dominant. All the weed management treatments significantly reduced the weed population over the weedy check. Significantly highest weed control efficiency and kernel yield under both foothill and mid hill conditions were observed in 2 hand weeding at 15 and 30 DAS with the corresponding values of 86.84%, 2535 kg/ha and 85.94%, 2980 kg/ha, respectively which was found to be statistically at par with application of tembotrione post emergence at 120 g/ha at 15 DAS under both the situations with the corresponding weed control efficiency and kernel yield values of 84.63%, 2496 kg/ha and 82.91%, 2890 kg/ha, respectively (Singh *et al.* 2012). Application of tembotrione at 120 g/ha at 15 DAS registered highest B:C ratio of 1.24 and 1.58 , respectively under foot hill and mid hill conditions (Table 1).

Table 1. Effect of post emergence tembotrione application on weed dynamics, kernel yield and B:C ratio of *Kharif* maize in rainfed foothill and mid hill conditions of Jammu and Kashmir

Treatment	Foot hill conditions				Mid hill conditions			
	Weed Population (no./m^2)	Weed control efficiency (%)	Kernel yield kg/ha	B:C ratio	Weed Population (no./m^2)	Weed control efficiency (%)	Kernel yield kg/ha	B:C ratio
Tembotrione at 120 g/ha at 15 DAS	37.00 (6.16)	84.63	2496	1.24	47.00 (6.91)	82.91	2890	1.58
Atrazine at 1 kg/ha at DAS	68.00 (8.31)	71.75	2227	1.05	83.67 (9.15)	69.58	2560	1.32
Pendimethalin at 1 kg/ha at DAS	115.33 (10.78)	52.08	2020	0.82	126.33 (11.28)	54.06	2410	1.16
2 Hand weeding at 15 DAS and 30 DAS	31.67 (5.69)	86.84	2535	0.82	38.67 (6.29)	85.94	2980	1.12
Weedy check	240.67 (15.54)	0.00	1450	0.46	275.00 (16.60)	0.00	1715	0.71
Weed free	1.0 (0.00)	100.00	2765	0.76	1.0 (0.00)	100.0	3250	1.05
LSD (P=0.05)	0.69	NA	226	NA	0.90	NA	192	-

*Figures in parenthesis are transformed values subject to "x+1 square root transformations, DAS: Days after sowing, NA: Not analysed

CONCLUSION

Hence, it can be safely concluded that post emergence application of tembotrione at 120 g/ha at 15 DAS has been found to be an efficient weed management tool for maize growers who either miss pre-emergence herbicidal application due to unfavourable weather conditions or could not afford the labour intensive hand weeding.

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Efficacy of herbicide mixture for weed management in Bt. cotton

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Cotton *(Gossypium hirsutum* L.) is an important natural fibre of commercial significance extensively grown in the world particularly in India and more so in Telangana state. Since, cotton crop has long growth cycle, it has to pass through frequent rains/irrigations and therefore, weed problem is a serious production constraint. Losses caused by weeds in cotton range from 50-85% depending upon the nature and intensity of weeds. The critical period of weed competition in cotton was found to be 15-60 days (Sharma 2008).Weeds can reduce lint quality due to additional trash and staining of fibers leading to low grades and discounted prices. To be successful, weed management systems require advance planting and timely execution. Any delay in application may mean reduced control, higher herbicide use rates and herbicide costs. Majority of herbicides available in the market are not broad spectrum herbicides. Hence we need to go for combination of herbicides or herbicide mixtures for broad spectrum weed control. Hence the present study was carried out to find out the efficacy of herbicide mixtures for proper and timely weed control in Bt cotton

METHODOLOGY

Field experiments were conducted at Professor Jayashankar Telangana State Agricultural University, Hyderabad during *Kharif*, 2011 and 2012 to study the efficacy of herbicide mixtures for weed management in *Bt.* cotton. The experiment was conducted in randomized block design with three replications. *Bt.* cotton hybrid Jadoo was sown with a spacing of 90 x 60 cm and the plot size was 5.4 x 4.8 m. The treatments consisted of pre mixed herbicide mixture containing pyrithiobac sodium + quizalofop ethyl at 75, 100 and 125 g/ha, pyrithiobac sodium at 62.5 g/ha, quizalofop ethyl at 50 g/ha as post emergence herbicides at 15 DAS, pendimethalin at 1.0 kg/ha as pre-emergence, hand weeding and unweeded control. Herbicides were applied using knap sack sprayer fitted with flat fan nozzle. In all the chemical treatments, one inter cultivation was done at 40 DAS.

RESULTS

The general weed flora infesting the experimental field consisted of *Cyperus rotundus* among sedge, *Cynodon dactylon, Dinebra arabica, Dactyloctenium aegyptium, Digitaria sanguinalis, Echinochloa colona* among grasses and *Amaranthus viridis, Parthenium hysterophorus, Trianthema* spp, *Digera arvensis, Commelina benghalensis and Celosia argentea* among broad leaved weeds. Results indicated that all the weed control treatments significantly reduced weed growth over unweeded control. Results further indicated that at 30 days after application, herbicide mixture having pyrithiobac sodium+quizalofop ethyl at 100 and 125 g/ha proved effective and was on par with hand weeding in reducing weed density, weed dry weight and in turn weed control efficiency and significantly superior compared to alone application of pyrithiobac sodium at 62.5 g/ha, quizalofop ethyl at 50 g/ha or pre-emergence application of pendimethalin at 1.0 kg/ha and unweeded control. Yield attributes like more number of sympodial branches, more number of bolls per plant, more boll weight and highest seed cotton yield was recorded from hand weeding which was on par with that of herbicide mixture containing pyrithiobac sodium + quizalofop ethyl at 100-125 g/ha and significantly superior to alone application of either pendimethalin at 1.0 kg or quizalofop ethyl at 50 g or pyrithiobac sodium at 62.5 g/ha. Un-weeded control recorded lowest seed cotton yield indicating the adverse effect of weed interference in cotton. These results are indicating the efficiency of herbicide mixtures for broad spectrum weed control in cotton and none of the herbicides showed any phyto-toxic effect on cotton and there was no residual effect of herbicide mixture on succeeding crops like green gram, maize and sunflower.

Table 1. Effect of herbicide mixture on weed control and seed cotton yield in *Bt* cotton

Treatment	Dose (g/ha)	Weed density (no/m^2)		Weed dry weight (g/m^2)	WCE (%)	Seed cotton yield (t/ha)	Weed index (%)
		BLWs	Grasses				
Un weeded control	-	12.00(3.60)	6.33(2.70)	46.02(6.85)	-	0.86	52.2
Hand weeding	-	2.00(1.73)	1.33(1.52)	5.32(2.51)	88.43	1.81	-
Pyrithiobac sodium + quizalofop ethyl 10% MEC (Premix)	75.0	6.67(2.76)	5.67(2.58)	19.51(4.53)	57.61	1.46	19.3
Pyrithiobac sodium + quizalofop ethyl 10% MEC (Premix)	100.0	2.33(1.82)	4.67(2.38)	8.80(3.13)	80.87	1.72	4.75
Pyrithiobac sodium + quizalofop ethyl 10% MEC (Premix)	125.0	2.00(1.72)	4.33(2.29)	7.25(2.87)	84.25	1.75	3.3
Pyrithiobac sodium10 % EC	62.5	5.33(2.51)	3.67(2.14)	23.93(4.99)	48.01	1.46	19.1
Quizalofop-ethyl 5 % EC	50.0	11.67(3.55)	5.33(2.51)	29.92(5.56)	34.98	1.38	23.8
Pendimethalin 30% EC	1000	7.33(2.89)	5.67(2.57)	27.43(5.33)	40.40	1.39	23.0
LSD (P=0.05)		0.41	0.48	0.38		0.92	

*Figures in parenthesis are "(n+1) value

CONCLUSION

Herbicide mixture containing pyrithiobac sodium + quizalofop ethyl at 100-125 g/ha can be recommended for broad spectrum weed control in cotton without any phyto-toxic effect on cotton and without any residual effect on succeeding crops.

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Technical Session 10

Herbicides persistence and soil health

Effect of herbicides on weeds, crop productivity, soil health and their persistence in vegetable-sugarcane intercropping system

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Intercropping has the potential to increase total system productivity, monetary returns, and resource utilization in long duration crops like sugarcane. Selection of intercrops for this purpose needs to be done carefully to avoid the risk of excessive inter-specific competition with sugarcane (Bueren *et al*. 2003). Weeds can reduce sole sugarcane yield by 12 to 83% in tropical conditions of western India (Pawar *et al*. 2004). Even though intercrops can provide weed suppression through competition, acceptance of intercropping by local growers would need development of effective weed management tactics. At present information on the selectivity and efficacy of herbicides for weed control in autumn sugarcane intercropped with vegetables is scarce and this is considered a serious knowledge gap. The suitability of vegetables (cabbage, peas & garlic) for intercropping in autumn planted sugarcane and the efficacy of herbicides for weed control in these intercropping systems was investigated over two years. Further effect of these herbicides on soil health and their residues in vegetables raised as intercrops in autumn sugarcane were also studied.

METHODOLOGY

The present experiment was conducted at Punjab Agricultural University Ludhiana during 2010-11 and 2011-12 on loamy sand soil, low in OC & available N and medium in available P & K. The treatments consisted of four cropping systems {sole sugarcane, sugarcane + cabbage (1:1); sugarcane + peas (1:2) and sugarcane + garlic (1:3)} in the main plots and six weed control treatments [oxyfluorfen 0.176 kg & 0.234 kg/ha pre-emergence (PRE), pendimethalin 0.562 kg & 0.75 kg/ha PRE, hand weeding {30 & 60 days after sowing (DAS) in cabbage and peas; 30, 60 & 100 DAS in garlic} and weedy check] in sub plots replicated thrice in a split plot design. Data on weed growth and crops yields were recorded. The effect of herbicide application on soil microbial population (bacteria, actinomycetes and fungi) was studied at 0, 15 and 30 days after spray. Persistence of pendimethalin and oxyfluorfen in soil and vegetables were analyzed by high performance liquid chromatograph (HPLC).

RESULTS

Intercropping of sugarcane with peas, cabbage and garlic produced cane yield (75.9 t/ha) statistically similar to sole sugarcane (81.1 t/ha) and intercrop yields of 6.43 t/ha for garlic, 7.67 t/ha for peas and 15.5 t/ha for cabbage (Table 1). Intercropping of these vegetables in sugarcane increased the net monetary returns by 1.74-2.66 fold as compared to sole sugarcane. Sugarcane + garlic system recorded.

The highest gross & net returns and benefit cost ratio. Averaged over two seasons, the intercropping of garlic increased the net returns by Rs 136548 /ha than sole cane; the corresponding figures for peas and cabbage intercropping systems were Rs 73860 and Rs 61388 /ha. Oxyfluorfen 0.234 kg and pendimethalin 0.75 kg/ha recorded effective control of weeds in these intercropping systems and were at par with hand weeding and significantly increased yield of cabbage, peas and garlic than under weedy check. The herbicides use increased net returns by Rs 11459-36263 /ha as compared with weedy check. The highest microbial population was observed in unsprayed plots as compared to those in herbicidal treatments. There was decrease in viable counts of bacteria, actinomycetes and fungi shortly after spray of herbicides and this effect was more pronounced with higher concentration of oxyfluorfen and pendimethalin; microbial populations however recovered within 30 days after application of herbicides. The residues of pendimethalin and oxyfluorfen in the mature vegetables were below detectable limit which is 0.05 mg/kg. The residues of herbicides in soil samples were found to be below the limit of quantification after 60 days in case of pendimethalin and after 45 days in case of oxyfluorfen.

Table 1. Effect of various treatments on weed growth, yield and economics of autumn sugarcane based intercropping systems (pooled data of two years)

Treatment	Weed dry* matter (g/m^2)	Cane yield (t/ha)	Intercrop yield (t/ha)	Cane equivalent yield (t/ha)	Cost of cultivation (x10^3 ` /ha)	Net returns (x10^3 ` /ha)	B:C	Soil microflora (30 DAS)**		
								Bacteria (x10^6)	Actinomycetes (x10^4)	Fungi (x10^3)
Intercropping treatment										
Sugarcane sole	272 a	81.1 a	-	81.1 c	110.4	81.3	1.75	41.9 b	34.4 b	33.2 a
Sugarcane + cabbage	268 a	83.1 a	15.5	112.5 b	123.8	142.7	2.16	43.0 ba	34.6 ba	33.4 a
Sugarcane + peas	123 b	78.3 a	7.67	121.8 b	134.7	155.2	2.15	44.1 a	35.8 a	32.7 a
Sugarcane + garlic	176 b	75.9 a	6.43	155.9 a	151.6	217.9	2.45	42.8 ba	34.6 ba	33.4 a
Weed control treatment										
Oxyfluorfen 0.176 kg /ha	236 ab	75.9 a	-	112.9 bc	129.9	137.8	2.07	43.0 a	34.3 a	32.4 b
Oxyfluorfen 0.234 kg /ha	187 b	80.9 a	-	123.7 a	130.4	162.6	2.26	42.6 a	35.6 a	33.9 ba
Pendimethalin 0.562 kg/ ha	231 ab	80.8 a	-	118.4 ba	129.2	151.6	2.18	42.4 a	34.4 a	34.0 ba
Pendimethalin 0.75 kg /ha	229 b	78.9 a	-	121.3 ba	129.5	158.2	2.23	42.9 a	35.3 a	30.0 c
Hand- weeding	49 c	81.2 a	-	123.3 a	133.3	159.3	2.20	43.8 a	33.4 a	33.8 ba
Weedy check	327 a	79.6 a	-	107.2 c	128.4	126.3	1.99	43.1 a	34.8 a	35.0 a

*Weed dry matter data were square root transformed before analysis; ** Days After Sowing

CONCLUSION

The intercropping of autumn sugarcane with garlic, peas and cabbage did not show any adverse effect on cane yield and enhanced the net monetary returns. In these intercropping systems, pre-emergence application of oxyfluorfen 0.234 kg or pendimethalin 0.75 kg/ha provided effective weed control and improved overall profitability. These herbicides reduced soil microflora temporarily that recovered within 3-4 weeks. Pendimethalin and oxyfluorfen did not leave any residue in the produce at the time of harvest of intercrops.

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Estimation of major herbicides in paddy field and ground water using GCMS-Tandem Mass Spectometry

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India is the second largest producer of rice (*Oryza sativa* **L.**) in the world., The crop, however is largely infested by wide variety of weeds which can cause more than 70% yield losses. Use of selective herbicides was found most effective in weed management (Asokaraja *et al.* 1995). In Haryana, consumption of pretilachlor has more than 70% share followed by butachlor with 15-20% than anilofos and oxadiargyl having less than 10% consumption (give reference and the absolute consumption figures of pretilachlor *etc.*). The excessive use of herbicides have several environmental constrains because of their residual effects. Along with regular monitoring of residual status of these herbicides, there should be some practices in crop cultivation pattern like introduction of *Sesbania* as green manuring which can reduce the residual effect of these chemicals and maintain soil health for long time (Duhan *et al.* 2014). Residues of pretilachlor, butachlor, anilofos and oxadiargyl were evaluated in soil, ground water, grains and straw from farmer's field. To support the persistence of pretilachlor residues in underground water it's leaching, adsorption and desorption behavior were also studied using state of art analytical technique GCMS-Tandem Mass Spectometry.

METHODOLOGY

The soil samples were taken at harvest time from farmer's field at various location of major rice-wheat growing regions of Haryana during the period. The samples were extracted, cleaned-up and estimated by GCMS/MS. Before final estimation a Multiple Reaction Monitoring (MRM) programme was developed on the basis of SCAN and Product Ion (PI) monitoring for pretilcahlor, butachlor, anilofos and oxadiargyl.

RESULTS

Retention time for pretilachlor, butachlor, anilofos and oxadiargyl was observed to be 18.55, 27.3, 22.5 and 36.4 min, respectively. Limit of detection (LOD) and limit of quantification (LOQ) were 1.0 and 3.0 ppb[d]. Average recovery experiments at 0.25 and 0.5 u/g fortification level revealed the recoveries of all herbicides to more than 80%. In shallow tube-well water, it was observed that 4 out of 21 sites were having pretilachlor residues ranging between 0.21 – 0.81 µg/ml (above MRL[e] - 0.1 µg/ml). Eight sites were having residues below MRL[e]. Rest of the samples show residue below detectable level. Butachlor residues were below MRL[e] value in shallow tube well water. No anilofos and oxadiargyl residues were found at any site. Residues of pretilachlor, butachlor, anilofos and oxadiargyl at 150 different locations were also tested in tube-well water having water table greater than 50 feet or more. No residues of these four major herbicides were observed above MRL[e].

Pretilachlor residues were found in harvest time soil samples within range 0.010 to 0.05 µg/g in 5 out of 107 sites at farmers' field. Rice grains were found to contain residues within range 0.11 to 0.052 µg/g (below MRL- 0.1 µg/g in rice) at 10 out of 107 sites. Four sites were found to contain residues between 0.010 to 0.293 µg/g in straw samples. No butachlor, oxadiargyl and anilofos residues were detected in harvest time soil, grain and straw of paddy. Low to moderate leaching potential of pretilachlor was observed at lower dose. But higher dose show good leaching in an experiment conducted under lab conditions so as to know the leaching behavior of pretilachlor. The results from adsorption/desorption behaviour of pretilachlor applied at different concentration from 10 to 50 µg revealed that the total amount of pretilachlor adsorbed decreased with increase in initial concentration from 10 to 50 µg, whereas amount of desorption increases with increase in concentration of application. This revealed the conclusion that pretilachlor has leaching behaviour. The amount of pretilachlor adsorbed in soil ranged from 39.76-45.7%, whereas desorption in soil ranged from 46.79% to 60.35%.

CONCLUSIONS

Presence of pretilachlor residues above permissible limits at 4 out of 21 sites in underground water, 10 out of 107 sites in rice grains within range 0.11 to 0.052 µg/g (below MRL- 0.1 µg/g in rice) and four out of 107 sites in straw samples between 0.010 to 0.293 µg/g is alarming situation for the policy makers before recommending weed management strategies. Persistence of the residues may be due to indiscriminate use without following good agricultural practices by the farmers or may be due to higher ground water re-cycling through tube-well irrigation

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Correlation and regression studies on herbicide movement in soil

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The movement of herbicides in soil is an important process that determines their fate in both soil and aquatic environments. The knowledge on movement of herbicide helps in prediction of the time and placement of herbicide. As alternatives to field study, different techniques have been used to characterize herbicide movement through soil. Among these soil column studies have been widely used to demonstrate herbicide leaching and distribution in several soil types under various conditions. Hence, a laboratory study was conducted to study the relative mobilities of oxadiargyl and butachlor in two different soils under two different moisture conditions in soil columns and worked out correlation and regression coefficients for herbicide mobility in soil.

METHODOLOGY

The study was conducted by taking soil columns as described by Harris (1996). Extraction and estimation of herbicide was done as per standard procedures. To estimate the effect of the independent variables like mean depth, time, type of soil and moisture conditions on the dependent variable *i.e*. movement of the herbicide following Multiple Linear Regression was formulated.

$Y=a_0+b_1x_1+b_2x_2+D_1x_3+D_2x_4$

Y = Movement of oxadiargyl/butachlor (mg), a_0 = intercept, x_1=Mean depth (cm)

x_2= Time (days), D_1= Dummy for type of soil (1 for alfisol, 0 for vertisol), D_2 = Dummy for type of moisture (1 for saturation, 0 for unsaturation)

After finding the significance of type of soil and type of moisture conditions, dummies were dropped and multilinear regression was carried out for the respective soil types and moisture conditions individually.

RESULTS

Correlation and Regression studies

Correlation studies revealed that, similar negative (r=-0.83) association between movement of herbicide with depth of soil in both the herbicides (Table 2). Though association between movement of herbicide with time was weak, it was higher in oxadiargyl (r=0.32) than butachlor (r=0.28). Further, movement of oxadiargyl with depth of soil was similar in saturated condition (r=-0.86) whether it is alfisol or vertisols. This phenomena was not noticed in butachlor. The strongest association between movement

of herbicide with depth of soil was noticed in butachlor in alfisol in saturated situation followed by vertisol under saturated conditions and weakest association was noticed in oxadiargyl in unsaturated conditions of both soils. The association between movement of herbicide with time was more in butachlor in vertisol under saturated conditions followed by oxadiargyl in alfisol under saturated condition and weakest association was noticed in oxdiargyl in vertisol under unsaturated conditions. Thus higher association between movement of herbicide with depth of soil and time

Fig. 1. Movement of oxadiargyl extracted (mg) at different depths and different days of leaching in Alfisol under saturated conditions

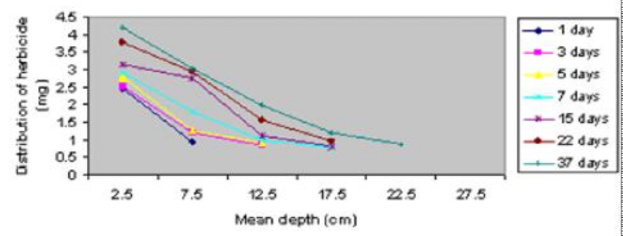

Table 1. Regression estimates and correlations for oxadiargyl and butachlor under different soil types and moisture conditions

Regression estimates	Oxadiargyl				Butachlor			
	Alfisol		*Vertisol*		*Alfisol*		*Vertisol*	
	Satura-ted	Unsaturated	Satura-ted	Unsaturated	Saturated	Unsaturated	Saturated	Unsaturated
Mean Depth (cm)	-0.124	-0.09	-0.113	-0.089	-0.124	-0.114	-0.162	-0.133
Time	0.035	0.021	0.028	0.016	0.032	0.030	0.051	0.032
Intercept	2.546	1.852	2.282	1.774	2.591	2.288	3.427	2.67
R^2	0.86	0.75	0.83	0.73	0.85	0.82	0.89	0.79
F	120.07	58.44	96.05	50.65	108.93	86.55	161.22	71.95
Correlations								
Movement with depth	-0.86	0.82	-0.86	0.82	-0.87	-0.85	-0.86	-0.84
Movement with time	0.34	0.27	0.30	0.21	0.31	0.31	0.39	0.29

N = 42 (Total observations for respective herbicides with stated conditions)

was noticed in butachor in comparision with oxadiargyl. So, movement of oxadiargyl in alfisol was higher with time in saturated conditions (r=0.34) than unsaturated conditions (r=0.27), whereas with depth was higher in unsaturated conditions (r=-0.82) than saturated condition (r=-0.86).

Multi Linear Regression for oxadiargyl was significant. R^2 value was 0.79, indicates that the independent variables taken into account has influence of 79% of the variation in the movement of oxadiargyl. For every unit increase in the mean depth has an effect of -0.105 on the movement of herbicides, where as time has effect of 0.025. In butachlor MLR was highly significant and independent variables contributed 82% of the variation in the movement of butachlor. Every unit increase in the mean depth has an effect of -0.133 on the movement of butachlor and 0.036 variation for every unit change with time. Thus mean depth with time had higher effect on movement of butachlor than oxadiargyl. Coming to movement of herbcides in different type of soil and under different moisture conditions, the movement of oxadiargyl or butachlor was highly influenced by depth of soil and time in saturated condition than unsaturated condition in both type of soils. For example the movement of oxadairgyl in alfisol under saturated condition was more effected by mean depth (b=-0.124) and time (b=0.035) than the unsaturated conditions where regression coefficients were -0.09 and 0.021 respectively. This similar trend was noticed in both herbcides in both soil types. Type of soil not found significant, shows that movement of oxadiargyl was not much affected by type of soil. In other words, oxadiargyl moved similarly in both the soil types.

Regression coefficients reveals that type of soil has significant effect on movement of butachlor than oxadiargyl. Further, depth of the soil (b=-0.133) and time (b=0.036) had higher effect on the butachlor than the oxadiargyl. Type of soil has significant effect on movement of butachlor than oxadiargyl.

Leaching of cyhalofop-butyl in sandy loam soil in field lysimeters

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Increasing use of herbicides may pose environmental problems through leaching. Leaching and transport of herbicides not only result in low weed control efficacy but enhanced risk of groundwater contamination. Cyhalofop-butyl, (butyl (R)-2-[4-cyano-2-fluorophenoxy) phenoxy propionate is anaryloxyphenoxy propionicclass of herbicide and used as post emergence herbicide for controlling a wide range of grassy weeds. As residues of many herbicides were found in groundwater (Miao *et al.* 2003, Sondhia 2014) it is apparent that there is significant transport of these chemicalsthrough the soil profile. Therefore, thisstudy was conducted in the field lysimetersto evaluate the impact of rains on cyhalofop-butyl leaching and soil physico-chemical properties.

METHODOLOGY

Experimental lysimeterswere set up at research field of Directorate of Weed Research, Jabalpur. The textural class of soil was sandy clay loam, having sand 67.32-66.31%, Silt 9.2-10.0%, clay 22.68-21.88% and organic carbon 0.369-0.280% at 0-225 cm depths. Cyhalofop-butyl [Emulsifying Concentrate (EC) 10%] was applied at 90 and 180 g/ha to lysimeters. Soil samples were taken from 0-25, 50-75, 75-100, 100-125, 125-150, 150-175, 175-200 and 200-225 cm depths at 3, 5, 10, 20, 30, 60 and 90 days after cyhalofop-butyl applications received 1633 mm rains. Leachates and soil samples collected at various depths were analyzed following the method of Sondhia (2014). Identification of degradation products of cyhalofop-butyl in soil and leachates was done by LC-MS/MS. Leaching data wasanalysedusing variance of analysis technique (ANOVA).

RESULTS

After 3 days of experiment approximately 253.2 mm of rainfall on the experimental field and a total of 0.0488 µg/g cyhalofop-butyl residues were found in upper depth (0-25 cm) and 0.0014, 0.0032, 0.0019 and 0.0022 µg/g cyhalofop-butyl residueswere moved down to lower 50-75, 75-100, 100-125 and 125-150 cm depths. After five days of application approximately 91.3 mm rains was received that resulted in leaching and degradation of cyhalofop-butyl through hydrolysis. Cyhalofop-butyl residues were found to bebelow the detection limit (0.001 µg/g) at 175-225 cm soil depths in initial days of sampling in both the application rates. After 20 days cyhalofop-butyl residues were found below the detection limit at various depths (Table 1). Statistically significant difference ($P<0.05$) and interaction were found in cyhalofop-butyl residues due to rain and two rates of application of cyhalofop-butyl on field Lysimeters. Higher concentrations of cyhalofop-butyl were found in the surface soil, followed by successively lower quantity at the lower depths. In the leachates, 0.48 and 0.104 µg/l of cyhalofop-butyl residues were found treated with 90 and 180 g/ha of cyhalofop-p-butyl, respectively. Similar findings were reported by Carabias Martinez *et al.* (2000). They monitored concentration of fifteen herbicides owing to their frequency and amounts used toxicity and persistence in river basins in the provinces of Zamora and Salamanca (Spain). After six months, presence of six out of the fifteen herbicides monitored was detected at levels ranging from the detection limit to 1.2 ìg/l as a result of agricultural activities as well as kind of crop and treatment period. Soil pH and EC were evaluated and interaction between doses verses herbicide movement at various depth at varying rainfall was observed. Cyhalofop-butyl application at 90 and 180 g/ha levels and subsequent rain caused leaching which resulted in the significant difference in soil pH and EC at various depths ($P<0.05$). Strong adsorption of cyhalofop-butyl to the soil together with the rapid degradation resulted in low potential for parent ester to move into lower depths. Hence after 20 d cyhalofop-butyl was not found in the soil in all the depths after its application. However its three degradation products, namely 2-[4-(2-fluoro-4-cyanophenoxy) phenol, 2-[4-(2-fluoro-4-cyanophenoxy) phenoxypropanoic acid and [R-(+)-2-(4-(4-carboxyl-2-fluoro-4-hydroxy-phenoxy) phenoxy) propanoic acid] were detected at various depths from soil.

CONCLUSION

High rains in the initial days of experiments caused leaching of cyhalofop-butyl and significant amount of residues in soil at various depths between 3 to 10 d, afterwards residues were found below detection level (0.001 ìg/g).Therefore, it can be concluded that at higher rain and saturated soil moisture conditions, cyhalofop-butyl can leach to subsurface soil and pose moderate leaching risk.

Table 1. Residues of cyhalofop-p-butyl at various depths in soil

Treatment	Residue (µg/g)			
	3 d	5 d	10 d	30 d
T_1	0.0105	0.0018	0.0016	<0.001
T_2	0.0129	0.0016	0.0033	<0.001
T_3 (control)	<0.001	<0.001	<0.001	<0.001
LSD (T*T)	0.009	0.0005	0.0008	
Depth (cm)				
Upper0-50cm()	0.0480	0.0061	0.0034	<0.001
50-75	0.0014	0.001	0.0031	<0.001
75-100	0.0032	<0.001	<0.001	<0.001
100-125	0.0019	0.0027	<0.001	<0.001
125-150	0.0022	0.0023	<0.001	<0.001
150-175	<0.001	<0.001	<0.001	<0.001
175-200	0.0021	<0.001	<0.001	<0.001
200-225	<0.001	<0.001	<0.001	<0.001
LSD (D*D)	0.0015	0.0011	0.0019	
LSD (T*D) (0.05)	0.022	0.0013	0.0022	

(D- Depth; T- Treatment; T_1- 90 g/ha; T_2- 180 g/ha; T_3- 0.0 g/ha)

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Effect of glyphosate formulations on earthworm and microflora in soil

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There is an increasing concern regarding the effects of glyphosate formulations particularly Roundup®, on non target organisms in the soil environment. Earthworms have the tendency to avoid the chemicals applied to the soil which help them to avoid the toxicity from pesticides and other chemicals. Microbial activity measurements appear as good indicators of the degree of pollution of contaminated soil. In view of the above facts, the present study was done to monitor the sensitivity of earthworms to varying concentrations of two glyphosate formulations namely Roundup® and Glycel®applied to lateritic soil and to study the effect of application of these chemicals on soil micro flora and soil enzymes.

METHODOLOGY

The study was a part of the M.Sc. thesis carried out in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University, Thrissur during the year 2013-14. The programme consisted of (1) laboratory experiment (2) pot culture study and (3) field experiment.The treatments consisted of two formulations of glyphosate (Roundup® and Glycel® each at two concentrations (6 and 12 ml/l equivalent to the general recommendation of 1.2 kg/ha and double thedose respectively) and a control set which were replicated four times. Laboratory and pot culture studies were conducted in completely randomized design and the field experiment was conducted in randomised block design .

The sensitivity of earth worm was studied by an avoidance test (ISO 2004) carried out in the laboratory in rectangular boxes of 20 x 10 x 10 cm [ISO N 281 (2004)] with 2mm sieved soil (sandy clay loam of Ultisol order). After application of treatment in one section of the box (using a plastic separator), ten adult earthworms (native earthworm *Perionyx excavatus*) were introduced along the centre line and left undisturbed for three days. On the fourth day, the separator was reintroduced and the number of earthworms in each section was counted and their net response was calculated [NR=C-T/10 x 100, where NR is the Net Response; C = total number of earthworms in control section; T = total number of earthworms in treated section and 10 = total number of earthworms introduced into the plastic container].

In the pot culture study, lawn grass was planted in mud potscontaining 7.5 kg soil mixed with 70 g of dried cow dung and 50 earthworms, and allocation of treatments was done to find out the effect of glyphosate formulations on earthworm population and soil microflora. Field experiment was laid out in plots of size 5 x 4 m in a banana field so as to study the effects of the above formulations on earthworms, soil microflora and dehydrogenase enzyme activity at 30 and 60 days after spraying.

RESULTS

The laboratory study showed that earthworms avoided both the formulations of glyphosate and more avoidance was for Roundup® at 12 ml/l. In the pot culture study, neither Roundup nor Glycel had any deleterious effects on the multiplication of earthworm, whereas both soil fungi and bacteria were affected. Roundup® at12 ml/l had more deleterious effect on soil fungi and bacteria.

In the field experiment,Roundup at 6 and 12 ml/l and Glycelat ml/l significantly reduced the fungal population in the soil at 30 DAS. These three treatments were on par and the percentage decline over control ranged from 39.8-52.2% . Lower dose of Glycel (6 ml/l) registered 13.97% decline in the soil fungi. However, at two months after spraying, fungal population was found increasing and the differences between the treatments became insignificant. Bacterial count and dehydrogenase enzyme activity in the soil were unaffected by glyphosate formulations used in the study.

CONCLUSION

The earthworms avoided the soil treated with both the formulations of glyphosate. Application of glyphosate formulations viz., Roundup as well as Glycelat the recommended dose of 1.2 kg/ha (6 ml/l) were safe for use under arable conditions, while higher dose caused some inhibitory effects on soil microflora.

Table 1. Effect of glyphosate on earthworm avoidance behavior

Treatment	Number of earthworms in the box		Average net response (%)
	Treated section	Untreated section	
Absolute control (Distilled water)	5.0*	5.0*	0.0*
Glyphosate (Roundup):6 ml/l	3.7	6.3	26.7
Glyphosate 41% SL (Roundup) :12 ml/l	2.7	7.3	46.7
Glyphosate 41% SL (Glycel) : 6 ml/l	3.7	6.3	26.7
Glyphosate 41% SL (Glycel): 12 ml/l	3.0	7.0	40.0

*Mean of four replicates

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Long-term effect of herbicides on enzymes and enzymatic activities in major soils under intensive and long-term fertilizer experiments

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It is well documented that pesticides are widely used against a range of pests infesting agricultural crops and herbicide that controls weeds is not the exception. According to Sarfraz Hussain *et al* (2009), through the review indicated that the effect of pesticides (including herbicides) is governed by factors like soil properties, nature and concentration of pesticide used, its activity and production of metabolites during metabolism in soil. Keeping this in view few (LTFE)* sites were selected to assess the impact of herbicide application on soil quality in terms of enzymatic activities due to differential dissipation rate as well as residue retention of herbicides in the soil. These long term fertilizer experiments under All India Coordinated Research Project (AICRP LTFE) are going on since 1972 covering major soil groups, cropping systems and different agroecological zones in India. Experiments also include use of herbicides as weed control treatments and for comparison hand weeding and herbicide application along with recommended dose of fertilizer were followed at experimental sites.

METHODOLOGY

Long term fertilizer experimental sites selected were namely, Vertisols at Jabalpur (Madhya Pradesh), Inceptisols of Barrackpore (West Bengal) and Alfisols of Bangalore (Karnataka) with #soybean-wheat, rice-wheat-jute and finger millet-maize cropping system, respectively. The recommended doses of fertilizers and other agronomic practices were followed as per standard package of practices. There are 10 treatments in each experiment. These are: 50% optimal NPK dose; 100% optimal NPK dose; 150% optimal NPK dose; 100% optimal NPK dose + hand weeding; 100% optimal NPK dose + zinc or lime; 100% optimal NP; 100% optimal N; 100% optimal NPK + FYM; Unmanured (Control). The herbicides (Imazethapyr at Jabalpur; trifluralin, fluchloralin and quizalofop at Barrackpore and isoproturon at Bangalore) were applied in each treatment except in hand weeding treatment at each LTFE site. The agronomic practices and plant protection measures were followed as per standard recommended practices.

RESULTS

Results indicated that dissipation constant of herbicide was highest in 100% NPK + FYM and the lowest in 100% N treatment while reverse was true for half life period with minimum values in 100% NPK + FYM and the maximum in 100% N alone. Thus, herbicide residues persist for longer period when FYM was added to the soil which may be due to absorption of herbicidal molecules by the organic matter. Keeping this in view studies on enzymatic activities were conducted as they are indicators of biological health. The analysis of enzymes and their activities include dehydrogenase, urease, fluorescein diacetate hydrolyzing activity and acid and alkaline phosphatase activities. The study indicated that these biological parameters reduced significantly after a week of herbicide application while treatments having un-weeded control and hand weeding maintained the same status as compared to initial status. However, enzymatic activities started recovering after two weeks of their application and recovered almost to the extent of respective initial level at harvest. Afterwards recovery was observed which may be due to adaptability of the microorganisms in utilizing these herbicides as a source of carbon, resulting in increasing microbial population and other enzymatic activities. Hussain *et al.* (2009) could not draw any concrete conclusion on effect of pesticides on microorganisms and their associated transformation of nutrients in soil as different groups of pesticides exhibit manifold variation in toxicity. However, in this study persistence of herbicide revealed that the residue in soils ranged from 0.10-0.63 µg/g in the field experiment in Alfisols. Rate of herbicidal molecule degradation was maximum in 100% NPK + FYM + lime treatment followed by 150% NPK treatment and 100% NPK + FYM treatment and least degradation was observed in control followed by 50% NPK treatment. Addition of lime to 100% NPK enhanced the rate of degradation.

CONCLUSION

From the study it is concluded that herbicide application has temporary adverse effect on growth and development of microbes in terms of population and enzymatic activities for initial period. However, it recovers gradually within two weeks of herbicide application and afterwards residual effect was negligible due to degradation of herbicides after grand growth stage of crop.

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Persistence of pyrazosulfuron-ethyl in soil under aerobic condition

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Many processes are involved in the dissipation of herbicides in the environment. Once applied to a field, herbicides are distributed in the environment by phase-transfer processes. The fate and behavior of herbicides in the environment and the plant system depend on their chemical and physical properties and on the nature of the environment in which the herbicide is distributed. The kinetics of pesticide degradation reaction must be considered in order to estimate the availability of a pesticide molecule for the decomposition. Half-life is a measure of the time required for a pesticide to drop half the original concentration (King and McCarty 1968). In the present studypersistence ofpyrazosulfuron-ethyl (10 WP) in soil was studied under aerobic condition.

METHODOLOGY

Studies were conducted in pot culture experiments under greenhouse condition. Soil application of pyrazosulfuron-ethyl (10 WP) was done with five different doses, *viz*. 25 (X), 50 (2X), 75 (3X) and 100 (4X) g/ ha applied at the time of sowing (as surface treatment)and the soil sampling was done at 0, 5, 10, 15 and 20 days after sowing. The herbicide residue level was determined in soil samples by using HPLC.

RESULT

The residue of pyrazosulfuron-ethyl in soil ranged from 79.22 to 12.00 x 10^{-3} mg /kg at 0 and 20 days respectively (Fig.1). At 2X, 3X and 4X dose the residue content was 153.65, 239.15 and 271.62 x 10^{-3} mg/kg at 0 days and 30.56, 59.76 and 89.51 x10^{-3} mg/kg respectively at 20 days after application

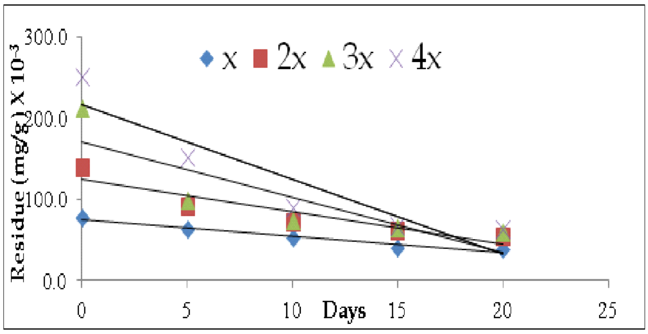

Fig. 1. Residues of pyrazosulfuron ethyl herbicide in soil at different time interval when treated with 25, 50, 75 and 100 g/ha pyrazosulfuron-ethyl

Table 1. Residues, half-life and regression equation of pyrazosulfuron ethyl in soil

Dosage g/ha	Residue X 10^{-3} (mg/kg)					Half-life ($T_{½}$)	Regression equation	R^2
	0 days	5 days	10 days	15 days	20 days			
25	79.22^{f}	37.13^{h}	30.91^{hi}	20.64^{ij}	12.00^{j}	7.96	y = -3.018x + 66.17	0.9593
50	153.65^{d}	55.30^{g}	39.69^{h}	33.96^{h}	30.56^{hi}	9.36	y = -5.350x + 116.1	0.8602
75	239.15^{b}	140.44^{e}	133.48^{e}	86.51^{f}	59.76^{g}	10.66	y = -8.254x + 214.4	0.7174
100	271.62^{a}	207.42^{c}	158.79^{d}	132.89^{e}	89.51^{f}	13.07	y = -8.774x + 259.8	0.8488

respectively. The half-life ($T_{1/2}$) was calculated from the best fit line of residual concentration versus time for soil at different levels of herbicide application as shown in Table 1. The half-life ($T_{½}$) ranged from 7.9 days for X, 9.3 days for 2X, 10.6 days for 3X and 13.0 days for 4X dose. The half-life increases with the increase in the dose of the herbicide and it was maximum when applied with 4X dose of herbicide (Fig. 1).

CONCLUSION

The study indicated that pyrazosulfuron-ethyl isa short-lived herbicide in the soil and is degraded relatively faster in aerobic condition.

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Bioefficacy of pre- and post-emergence herbicides in greengram and their residual effect on succeeding mustard

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Weed emergence in green gram begins almost with the crop emergence leading to crop-weed competition from initial stages. The magnitude of loss as a result of crop-weed competition depends upon type of weed species, associated with crop, their densities and duration of competition with crops. Although pre-emergence use of pendimethalin at 1.0 kg/ha has been found effective to control weeds in green gram but a residual herbicide is needed to control second flush of weeds emerging after rains. Keeping it in view, herbicides imazethapyr alone or in combination with imazamox and pendimethalin as pre-mixture with imazethapyr were tested under pre and post emergence conditions and compared with pendimethalin alone

METHODOLOGY

The present studies were conducted during *Kharif* season of 2012 and 2013 at Department of Agronomy, CCS HAU, Hisar under irrigated conditions. The soil of the experimental field was sandy loam in texture, having pH 8.1, low in organic carbon (0.3%) and nitrogen (180 kg/ha), medium in available phosphorus (18 kg/ha) and high in potassium (370 kg/ha) content. Eleven treatments were pendimethalin at 1.0 kg/ha and pendimethalin+ imazethapyr (RM) at 800-1000 g/ha as pre-emergence. Post-emergence treatments included different doses of imazethapyr at 50 and 70 g/ha, imazethapyr+imazamox (RM) at 60-80 g/ha and compared with weed free and weedy checks. Green gram cultivar Satya was sown in second fortnight of July and harvested in first week of October during both years of study. Post mergence herbicides were applied at 23 DAS (2-3 leaf stage of weeds) by knapsack sprayer fitted with flat fan nozzle using 375 l/ha water. Crop yield and yield parameters were recorded at maturity. To study the residual carryover effect of herbicides applied in green gram, mustard crop was planted in same layout with slight disking after harvest of green gram.

RESULTS

Experimental field was dominated by *Echinochloa colona* constituting during 2012 but during 2013, *Trianthema portulacastrum* was the most dominant weed with 90-98% of total weed flora. Other weeds present were *Cyperus rotundus* and *Dactyloctenium aegyptium*.

During 2013-13, mazethapyr at 70 g and its combination with imazamox at 80 g/ha used at 3-4 leaf stage were more effective against this weed than other treatments. Although post emergence application of both these herbicides caused phytotoxicity to green gram in terms of yellowing, bud necrosis and crinkling of leaves which mitigated within 15 days after application in all treatments. During 2013, all pre-emergence herbicides treatments proved very effective against predominant weed *T. portulacastrum* and pre-emergence use of imazethapyr with pendimethalin at 900 and 1000 g/ha gave 91-98% control of weeds during 2012 and 2013. This is in agreement with results of Chandakar *et al.* (2014) who reported effectiveness of early post-emergence application (15-20 DAS) of imazethapyr at 40 g/ha and pendimethalin + imazethapyr at 1.0 kg/ha as PRE against weeds in black gram in clay texture soils of Raipur. None of the herbicide treatment proved effective against *C. rotundus*. During 2012, seed yield was maximum (1.50 t/ha) in weed free treatment which was at par with post emergence application of imazethapyr at 50 and 70 g/ha and imazethapyr + imazamox (RM) at 60 g/ha but during 2013, among herbicide treatments, maximum seed yield of green gram (1.50 t/ha)was obtained with pre-emergence used of ready mixture of pendimethalin and imazethapyr at 1000 g/ha which was at par with its lower use rate of 900 g/ha but significantly higher than all other herbicide treatments. No residual carry over effect of these herbicides was observed in succeeding mustard crop.

Table 1. Effect of different treatments on weed control efficiency (WCE), seed yield in green gram and plant height and seed yield of mustard

Treatment	Dose (g/ha)	Application time	WCE (%) 30 DAS		Yield (t/ha)		Mustard plant height (cm)		Mustard yield (t/ha)	
			2012	2013	2012	2013	2012-13	2013-14	2012-13	2013-14
Pendimethalin	1000	PRE	69.9	84.3	0.90	1.40	22.4	22.4	1.84	1820
Imazethapyr	50	3-4 LS	94.5	17.2	1.44	1.24	20.1	21.6	1.92	1860
Imazethapyr	70	3-4 LS	97.2	17.2	1.48	1.28	22.0	21.5	1.95	1960
Imazethapyr +pendimethalin (RM)	800	PRE	93.9	86.9	1.40	1.44	20.8	22.0	1.89	1950
Imazethapyr +pendimethalin (RM)	900	PRE	98.0	91.0	1.41	1.46	22.0	21.7	1.82	1800
Imazethapyr +pendimethalin (RM)	1000	PRE	98.6	93.6	1.42	1.50	23.4	22.4	1.84	1900
Imazethapyr + imazamox(RM)	60	3-4 LS	95.9	35.1	1.45	1.37	21.9	20.8	1.95	1920
Imazethapyr + imazamox(RM)	70	3-4 LS	92.1	17.5	1.37	1.42	20.4	21.6	1.87	1860
Imazethapyr + imazamox(RM)	80	3-4 LS	96.1	14.1	1.36	1.44	21.3	22.0	1.88	1878
Weed free	-	-	100	100	1.50	1.58	22.4	22.0	1.88	1872
Weedy check	-	-	0	0	216	340	20.1	21.2	1.88	1920
LSD (P=0.05)			-		73.1	35.0	NS	NS	NS	NS

Transformed values (" x + 1), original values are given in parenthesis DAT: Days after treatment

CONCLUSION

Pre-emergence application of ready mix combination of pendimethalin + imazethapyr at 1000 g/ha can safely be used to control weeds in green gram without any residual carry over effect on succeeding mustard crop.

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Herbicidal effects on soil and crop health in cotton

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Use of herbicides has promised better weed management in cotton. But, in other hand, their indiscriminative use negatively correlates with the crop as well as soil health also. Herbicidal spray may cause injury on the crop canopyleading to reduced crop growth and development. Similarly, herbicidal spray on the soil surface may hinder the soil microbial population and thus decreases themicrobial activity in the soil. The study of herbicidal influence onthese parameters gives an idea about compatibility of herbicide with crop, its lethal effect on soil microbes and thus helps in herbicidal selection for better weed management. Crop phytotoxicty and soil dehydrogenase activity were evaluated as crop and soil health test parameters to understand compatibility of herbicides with cotton.

METHODOLOGY

The field experiment was conducted during *Kharif* 2012-13 at Agricultural College Farm, Bheemarayanagudi, Shahapur (Karnataka) under UKP Command area. The soil was medium deep black soil, medium in organic carbon (0.7%), low in available nitrogen (252 kg/ha), medium in available phosphorus (33 kg/ha P_2O_5) and high in potash (297 kg/ha K_2O). The experiment comprised of 14 treatments, *viz*. unweeded check, weed-free check, diuron 1 kg/ha PRE *fb* IC and HW at 30, 45 and 60 DAS, pendimethalin 0.68 kg/ha PRE *fb* IC and HW at 45 DAS, propaquizafop 0.1 kg /ha POE at 20 and 40 DAS *fb* IC at 60 DAS, quizalofop-p-tefuryl 0.044 kg/ha POE at 20 and 40 DAS *fb* IC at 60 DAS, fenoxaprop-p-ethyl 0.1 kg/ha POE at 20 and 40 DAS *fb* IC at 60 DAS, quizalofop ethyl 0.05 kg/ha POE at 20 and 40 DAS *fb* IC at 60 DAS, pyrithiobac sodium 0.125 kg/ha POE at 20 and 40 DAS *fb* IC at 60 DAS, pendimethalin PRE *fb* propaquizafop 0.1 kg/ha POE at 30-35 DAS *fb* IC at 60 DAS, pendimethalin PRE *fb* quizalofop-p-tefuryl 0.044 kg/ha POE at 30-35 DAS *fb* IC at 60 DAS (T_{11}), pendimethalin PRE *fb* fenoxaprop-p-ethyl 0.1 kg/ha POE at 30-35 DAS *fb* IC at 60 DAS, pendimethalin PRE *fb* quizalofop-ethyl kg/ha POE at 30-35 DAS *fb* IC at 60 DAS, and pendimethalin *fb* pyrithiobac sodium 0.125 kg/ha POE at 30-35 DAS *fb* IC at 60 DAS. The experiment was laid out in a randomized complete block design with three replications. Cotton (cv. Arya *Bt*BG II) was sown on 10th July of 2012 with a spacing of 90 cm × 60 cm. The phytotoxicity injury ratings (Rao 1986) and dehydrogenase activity (Cassida *et al*. 1964) were analysed to study the effect of herbicides on crop and soil.

RESULTS

At 15 DAS, diuron 1.0 kg/ha PRE recorded higher crop phytotoxicity (3.33) compared to pendimethalin 0.68 kg/ha (2.00) which progressively receded at 25 DAS. The effects still persisted with diuron than with pendimethalin, however from 35 DAS onwards there was more recovery and by 60 days none of such impacts were noticeable.

At 25 DAS, unweeded check and weed free check recorded the highest (21.34 µg and 21.07 µg/g soil/day) amount of TPF formed. These were on par with all other treatments except treatments followed with pre-emergence herbicides. The least soil dehydrogenase activity (16.30 and 17.20 µg TPF/g soil/day) was noticed in recommended practice *i.e*. diuron 1 kg/ha and pendimethalin 0.68 kg/ha. The highest soil dehydrogenase activity (22.96 µg TPF/g soil/day) was again noticed in weed free check at 45 DAS and it was on par with all other treatments. So no significant differences were observed among the treatments. The same trend was continued at 60 DAS and at 90 DAS with reduced activity.

Table 1. Crop phytotoxicity and soil dehydrogenase activityin cotton field as influenced by weed control treatments

Treatment	Crop phytotoxicity					Soil dehydrogenase activity (µg TPF/g soil/day)				
	15 DAS	25 DAS	35 DAS	45 DAS	60 DAS	25 DAS	45 DAS	60 DAS	90 DAS	At harvest
Unweeded Check	0.00	0.00	0.00	0.00	0.00	21.34	22.77	25.49	17.73	9.41
Weed free Check	0.00	0.00	0.00	0.00	0.00	21.07	22.96	25.04	17.28	8.32
Diuron *fb* IC and HW	3.33	2.00	0.00	0.00	0.00	16.33	21.88	24.14	17.11	9.61
Pendimethalin *fb* IC and HW	2.00	1.00	0.00	0.00	0.00	17.55	21.80	24.24	17.14	9.28
Propaquizafop (Twice) *fb* IC	0.00	1.00	0.33	0.33	0.00	20.80	21.77	21.59	17.05	8.75
Quizalofop p tefuryl (Twice) *fb* IC	0.00	0.67	0.33	0.00	0.00	20.57	22.30	24.03	17.05	8.39
Fenoxaprop p ethy (Twice) *fb* IC	0.00	1.00	0.67	0.33	0.00	20.75	21.88	24.15	17.23	9.41
Quizalofop ethyl (Twice) *fb* IC	0.00	1.00	0.67	0.33	0.00	20.12	22.06	25.29	17.37	8.26
Pyrithiobac sodium (Twice) *fb* IC	0.00	1.33	0.33	0.00	0.00	20.08	22.96	25.08	17.42	8.88
Pendimethalin *fb* Propaquizafop *fb* IC	2.00	1.33	0.67	0.33	0.00	17.56	22.07	24.75	17.01	9.10
Pendimethalin *fb* Quizalofop p tefuryl *fb* IC	2.00	1.33	0.33	0.33	0.00	17.62	21.84	24.88	17.48	8.25
Pendimethalin *fb* Fenoxaprop p ethyl *fb* IC	1.67	1.33	0.67	0.00	0.00	17.80	22.04	24.21	17.38	8.63
Pendimethalin *fb* Quizalofop ethyl *fb* IC	1.67	1.33	0.67	0.33	0.00	17.34	22.35	23.91	17.24	8.60
Pendimethalin *fb* Pyrithiobac sodium *fb* IC	1.67	1.33	0.00	0.33	0.00	17.20	21.94	24.32	17.21	8.62
LSD (P=0.05)						1.51	1.27	1.46	1.36	1.00

CONCLUSION

Herbicides did not showany recognizable phytotoxicity symptoms on cotton. Only pre emergent herbicides had little injurious effect initially below the threshold level from which the crop recovered later. Similarly, soil dehydrogenase activity was also not affected by post- emergence herbicides, while only pre-emergence herbicides initially caused temporary decrease in the activity and was recovered in later days.

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Monitoring of herbicide residues in vegetable crops

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Vegetables play a major role in Indian agriculture by providing food, nutritional and economic security and more importantly, producing higher returns per unit area and time. In addition, vegetables have higher productivity, shorter maturity cycle, high value and provide greater income leading to improved livelihood. For better production and aesthetic value, farmers are using a large amount of herbicides during the entire period of growth of vegetables, even at fruiting stage and many a times farmers ignore recommended dose of herbicides. Continual and injudicious use becomes the reason of accumulation of herbicide residues in the vegetables which could be consumed by human beings directly (Kumari *et al.* 2003). The problem of residues accumulation needs more attention in vegetables because most of time these are consumed either raw or without much storage time. Proper use of chemicals is enforced by periodic monitoring programme for the protection of consumers and to evaluate the quality of food especially vegetable crops. Therefore, present research work was undertaken with an objective to survey herbicide usage and their concentration in vegetables of two districts of Himachal Pradesh.

METHODOLOGY

Ten major vegetable producing blocks of two districts, *i.e.* Kangra and Mandi of Himachal Pradesh were surveyed through PRA technique. Samples (1-2 kg each) were collected from direct farmer's field and local market and stored at -10^{0}C for further analysis. Amultiresidue GC method was developed for commonly used herbicides metribuzin, pendimethalin, oxyfluorfen and alachlor in vegetables crops. The prepared samples were analyzed by Perkin Elmer GC Model Clarus 500 equipped with ^{63}Ni Electron Captured Detector (ECD). For residue estimation collected vegetables samples were extracted and analyzed. The recovery studies were also carried out in order to establish the reliability of the analytical method used and also to know the efficiency of extraction in the present study.

RESULTS

In all surveyed ten blocks, beans, tomato, cucumber, capsicum, okra, chillies, brinjal, cauliflower, cabbage, garlic, onion and turnip were commonly grown vegetables. Alachlor was the main herbicide used by the farmers to control different weeds of vegetable crops. A total of 78 farmers were selected for collection of vegetables in these ten blocks for residue studies. Total 251 samples including 16 samples from local market were collected. The average recoveries following the analytical procedure were 81.3% for metribuzin, 88.2% for pendimethlin, 101.1 % for alachlor and 90.6% for oxyfluorfen respectively. Maximum samples of tomato (55) were analyzed and out of which 6 samples were contaminated with alachlor residues (0.012- 0.1 ppm) and 3 samples were contaminated with metribuzin residues (0.1ppm). Total 30 samples of beans were analyzed out of which 4 bean samples were found to be contaminated with Alachlor (0.020- 0.061 ppm) and 2 samples with metribuzin (0.007- 0.014 ppm). Out of 31 samples of cucumber, 4 samples were found to be contaminated with Alachlor (0.01-0.04 ppm). In chilies, onion, potato, okra, cauliflower, peas, beans and bittergourd only one sample of each was found to be contaminated. Out of 251 vegetable samples only 3 samples were found to be contaminated with alachlor herbicide residue above the MRLs.

CONCLUSION

The findings of present study revealed that 1.2% of samples were contaminated above MRL values. Therefore, it is important to continue the herbicide residue monitoring programme.

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Sequential application of herbicides on yield and weed flora of vegetable pea under varying levels of crop residues

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Vegetable pea (*Pisum sativum* L. var. *arvense*) called as 'pois proteagineux' in French, 'matar' in Hindi, is an important winter season legume crop largely grown in the cooler temperate zones in northern India. It provides nutritious food rich in protein. A 100 g of dried edible portion of grains contain 1.8 g fat, 62.1 g carbohydrate, 22.5 g protein, 0.15 g riboflavin, 0.72 mg thiamine, 2.4 mg niacin, 64 mg calcium and 4.8 mg iron (Ali *et al*. 2014). It is an important food supplement of the majority Indian population who are vegetarian. Owing to its initial slow growth habit and short duration, weeds comprising of grassy, broadleaved and sedges compete with it and cause considerable yield losses. Weed control using pre-emergence herbicides is not sufficient for effective weed control in peas. Studies involving pre and post-emergence herbicides in combination with other methods of weed control are also scant in the literature. Therefore, this experiment was undertaken with the objective to find out weed control effects of pre and post-emergence herbicides in combination with residue retention or conoweeding on growth and productivity of vegetable pea.

METHODOLOGY

The experiment was laid out in a randomised block design (RBD) replicated thrice with twelve treatment combinations i.e., pendimethalin 1.0 kg/ha (PE), pendimethalin 0.5 kg/ha (PE) + residue 2t/ha, pendimethalin 0.5 kg/ha (PE) + residue 4 t/ha, pendimethalin 0.5 kg/ha (PE) + residue 2t/ha + quizalofop-p-ethyl 0.05 kg/ha as POE, pendimethalin 0.5 kg/ha (PE) + residue 2 t/ha + imazethapyr 0.075 kg/ha as POE, pendimethalin 0.5 kg/ha (PE) + imazethapyr 0.075 kg/ha as POE, pendimethalin 0.5 kg/ha (PE) + quizalofop-p-ethyl 0.050 kg/ha as POE, unweeded control, weed free, two hand weedings (farmers practice, 20 and 40 DAS), pendimethalin 1.0 kg/ha (PE) + one conoweeding (25 DAS), two conoweedings (20 and 40 DAS) . Pre-emergence herbicide was applied within 2 days after sowing and post-emergence application was done 30 DAS. Vegetable pea cv. *Pusa Shree* was sown on 15th October, 2014 following recommended package of practices for sowing of a healthy crop. The various growth and yield parameters of peas were recorded as per standard procedures and analysed statistically for their interpretation. The data on weed species present, weed density and their dry matter production was also recorded and presented.

RESULTS

It was observed that weed free check caused the greatest reduction in weed density and weed dry matter production. However, the application of pendimethalin 0.5 kg a.i./ha (PE) + residues 2 t/ha + quizalofop 0.050 kg/ha as POE, pendimethalin 0.5 kg/ha (PE) + residues 2 t/ha + imazethapyr 0.075 kg /ha as POE, pendimethalin 0.5 kg/ha (PE) + residues 4t/ha and pendimethalin 0.5 kg/ha (PE) + residues 2 t/ha also caused significant reduction in density and dry-matter accumulation of weeds over unweeded control (Table 1).

The pendimethalin 0.50 kg/ha (PE) + residues 2 t/ha + imazethapyr 0.075 kg/ha as POE, resulted in significantly higher pod yield (3.89 t/ha) compared to unweeded control (2.09 t/ha). The pod yield of this treatment was higher and comparable with weed free check. The yield loss due to uncontrolled growth of weeds as compared to pendimethalin 0.5 kg/ha (PE) + residues 2 t/ha + imazethapyr 0.075 kg/ha applied as post emergence was 46%.

Table 1. Growth, yield and yield attributes of vegetable peas as influenced by different weed control treatment

Treatment	Weed density/ m^2	Dry matter of weeds (g/m^2)	No of pods/ plant	Pod length (cm)	No of seeds/ pod	Green pea yield (t/ha)
Pendimethalin at 1.0 kg/ha (PE)	100	14.15	20.33	6.34	5.33	2.57
Pendimethalin at 0.5 kg/ha (PE) + residue at 2 t/ha	78	10.01	22.00	6.34	5.78	3.70
Pendimethalin at 0.5 kg/ha (PE) + residue at 4 t/ha	56	8.0	23.00	6.78	6.00	3.75
Pendimethalin at 0.5 kg/ha (PE)+ residue at 2 t/ha + quizalofop-p-ethyl at 0.050 kg/ha as POE	40	6.3	23.67	6.45	5.99	3.82
Pendimethalin at 0.5 kg/ha (PE) + residue at 2 t/ha + imazethapyr at 0.075 kg/ha as POE	40	6.7	23.67	6.67	6.33	3.89
Pendimethalin at 0.5 kg /ha (PE) + imazethapyr at 0.075 kg/ha as POE	106	15.11	21.00	5.44	5.00	2.57
Pendimethalin at 0.5kg/ha (PE) + quizalofop-p-ethyl at 0.050 kg/ha as POE	94	14.22	22.00	5.05	6.00	2.43
Unweeded control	124	18.25	17.00	4.83	4.67	2.09
Weed free	00 (0.07)	0.00(0.07)	23.67	6.30	6.33	3.93
Two hand weedings (farmer's practice)	60	8.2	22.00	6.22	5.67	2.65
Pendimethalin at 1.0 kg/ha as PE + one conoweeding	76	12.35	20.00	6.34	6.00	2.88
Two conoweedings	62	9.12	20.00	5.89	5.33	2.50
LSD (P=0.05)	30	2.8	4.6493	1.1446	NS	1.0227

PE = Pre-emergence, POE = Post emergence

CONCLUSION

It can be concluded that the application of pendimethalin 0.5 kg/ha (PE) + residue 2 t/ha + imazethapyr 0.075 kg/ha as POE was most effective for controlling weeds, improving pod yield and productivity of vegetable peas. The next best alternative weed control measure could be pendimethalin 0.5 kg/ha (PE) + residue 2 t/ha + quizalofop-p-ethyl 0.050 kg/ha as POE.

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Technical Session 11

Management of problematic (including alien invasive and parasitic) weeds

Efficacy of shoot leachates of potential allelopathic plants on famine weed

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Famine weed (*Parthenium hysterophorus* L.) is an annual herbaceous plant supposed to have originated in North East Mexico and during the last ten years it has spread to Ethopia, Pakistan and Nepal. Presence of certain strong allelochemicals in allelopathic plants like *Cassia occidentalis*, *Calotropis procera* and *Croton bonplandianum*, have subsequent influence and appears to affect *Parthenium* to some extent. Shoot leachates of allelopathic plants in both solvents (methanol and ethanol) showed significant inhibition on seed germination, plumule and radicle length.

METHODOLOGY

The experiment was conducted in St. John's College, Agra (2013-2014). Fresh leaves of *C. occidentalis. C. procera* and *C. bonplandianum* were collected from six different sites of Agra (Figure 1) and washed with tap water and then distilled water to remove dirt and dust and dried naturally. The fresh leaves (20 g) were soaked in 100 ml of both methanol and ethanol solvents each under aseptic conditions for 15 days and placed in conical flask under refrigeration at 8±1^{0}C. After the stipulated period, the solvent leachates were filtered through three layers of muslin cloth/ cheese cloth to remove debris. Two different concentrations (50 and 100%) of leachates were prepared and used for bioassay. Pure methanol and ethanol blanks were used as control. Seeds of *Parthenium* were collected from different sites of Agra, thoroughly washed with tap water , sterilized with 0.1% $HgCl_2$ for 10 minutes and again washed with distilled water for 4 – 6 times. Viable *Parthenium* seeds were divided into 6 replicates of 15 seeds each and were placed on filter paper in sterilized petridishes, moistened with distilled water and 5 ml of methanol and ethanol shoot leachates of different concentrations were used for further moistening and treatment. All the seed lots were allowed to germinate in 12 cm petridishes. Petridishes were covered and placed in sealed polythene bags to prevent further loss of volatile compound (allelochemicals) and kept undisturbed for 15 days at 25±2ºC. The number of germinated seeds, growth of plumule and radical was also recorded after 15 days.

RESULTS

The significant reduction in seed germination of *Parthenium* (4.75%) was obtained in 100% ethanol shoot extract of *C. occidentalis fb C. procera* (5.5%), *and C. bonplandianum* (7.25%). The significant inhibition in plumule length was observed in *C. occidentalis* (4.5 cm) at 100% concentration of leachate in ethanol whereas minimum (10.15 cm) was observed in *C. bonplandianum* at 50% concentration of methanol shoot extract. The significant inhibition in radicle length was observed in *C. occidentalis* (3.9 cm) at 100% concentration of leachate in ethanol whereas minimum (9.98) was observed in *C. bonplandianum* at 50% concentration of methanol shoot extract (Table 1). Jaggi *et al.* (2010) also observed the similar results.

Table 1. Effect of methanol and ethanol shoot leachates of competitive plants shoots, on seed germination and seedling growth of *Parthenium*

Competitive Plants	Concentration (%)	Germination (%)		Methanol shoot leachates		Ethanol shoot leachates	
		Methanol	Ethanol	Plumule length (in cm)	Radicle length (in cm)	Plumule length (in cm)	Radicle leng (in cm)
C. occidentalis	50	6.50±(2.3)	5.24±(1.8)	6.15±(3.0)	5.15±(1.5)	4.75±(1.5)	4.00±(0.5)
	100	5.12±(0.5)	4.75±(1.5)	5.75±(1.5)	4.95±(2.3)	4.50±(2.0)	3.90±(1.5)
C. procera	50	8.24±(0.5)	6.10±(2.3)	8.00±(2.0)	7.90±(2.0)	5.98±(0.5)	5.00±(1.2)
	100	6.00±(1.5)	5.50±(2.0)	7.55±(0.5)	7.00±(0.5)	5.75±(2.0)	5.00±(1.5)
C.	50	10.25±(1.5)	9.15±(1.8)	10.15±(1.2)	9.98±(1.3)	9.00±(0.2)	8.90±(1.5)
bonplandianum	100	8.75±(2.3)	7.25±(0.5)	9.25±(2.0)	9.15±(1.3)	8.95±(0.2)	8.25±(0.5)
Control	-	93.33±(0.0)	90±(0.0)	13.14±(1.3)	9.00±(0.2)	12.35±(2)	10.75±(1.5

Values in parenthesis are ± SD of mean.

CONCLUSION

It was concluded that allelopathic plants does have some potential in curbing the population of this obnoxious weed.

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Pogostemon essential oil as a natural herbicide

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Volatile/essential oils from aromatic plants have been in use in food, flavour, cosmetic and pharmaceutics since antiquity. They have been involved in ecological patterning observed under natural conditions and are potent germination inhibitors. Due to their environmentally benign nature and phytotoxicity, there has been resurgence of interest in elucidating their role as natural herbicides. Such studies are highly significant in view of the environment and health concerns and increasing incidence of herbicide-resistant weeds linked to wide spread use of synthetic herbicides. With this background in mind, we conducted a series of experiments under laboratory and green house conditions to evaluate the phytotoxicity and weed suppressing ability of essential oil extracted from *Pogostemon benghalensis* (Family Lamiacaeae), an aromatic plant growing wildly along mountain slopes in India.

METHODOLOGY

The oil was extracted from leaves by hydro-distillation using Clevenger's apparatus (Singh *et al*. 2009a) and analyzed by gas chromatography (GC) and gas chromatography–mass spectroscopy (GC–MS) as per Singh et al. (2009b). Pre-emergent activity of oil was determined under laboratory conditions using oil vapors (0.25 –2.5 mg/ml) in Petri dishes, while post-emergent activity was evaluated in terms of visible injury, content of total chlorophyll and energy metabolism after spray treatment of oil (0.5–5%, v/v) on 15 days old plants of test weeds (*Parthenium hysterophorus* and *Chenopodium album*) under natural experimental dome conditions.

RESULTS

Pre-emergent activity of oil

Germination of *Parthenium hysterophorus* and *Avena fatua* decreased with increasing concentrations of *Pogostemon* oil. A complete inhibition in seed germination was observed in response to 2.5 mg/ml oil. Seedling growth, chlorophyll content and cellular respiration of test weeds also decreased significantly with increased concentrations of oil.

Post-emergent activity of oil

In order to explore herbicidal effects of *Pogostemon* oil, its emulsion was sprayed on 15 days old plants of *Chenopodium album* and *A. fatua* grown in pots. Visible injury 1 and 3 weeks after spraying increased with increased concentration of volatile oil from 0-5%. At concentrations 2.5 and 5%, *Pogostemon* oil showed maximum toxicity where a complete killing of *C. album* plants was observed. With the passage of time, plants treated with 0.5 and 1% oil were able to partially recover, though their growth and development were greatly reduced. However, at 2.5 and 5%, plants died after 3 weeks. At 1, 2 and 3 weeks after spraying, chlorophyll content and cellular respiration decreased with increased concentration of volatile oils up to 0.5–5%.

Table 1. Effect of *Pogostemon* oil (after 1 and 3 weeks of spray) on injury level of test weeds

Concentration (%)	*P. hysterophorus*		*C. album*	
	1 week	3 weeks	1 week	3 weeks
0	0	0	0	0
0.5	+	0	++	+
1.0	++	+	+++	++
2.5	+++	++	+++++	+++++
5.0	+++	++	+++++	+++++

+: injury level in the range of 0-20%; ++: 20-40%; +++: 40-60%; ++++: 60-80%; +++++: 80-100%

CONCLUSION

From the present study, it can be concluded that volatile oil from *Pogostemon* exhibits strong phyto-toxicity and weed suppressing ability and hence could be useful natural plant products for developing bio-herbicides.

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Determining the management of *Papaver dubium*, an invasive weed in Japan by using cyanamide

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Exotic long-headed poppy (*Papaver dubium* L.) an emerging invasive weed of Japan, first identified from Tokyo in 1960's, has spread almost all parts of Japan. Seed germination plays vital role in facilitating the rapid acclimation of this weed. *Papaver dubium* produce large number of seeds in April/May. Cyanamide is known to enhance the germination of weeds like *Echinochloa oryzicola*, in order to be exposed to and killed by low winter temperatures (Morita 2001). Earlier reports indicated that seeds of *Papaver dubium* germinate either in autumn or in spring and that autumn germinators do not survive a severe winter. This natural phenomenon can be exploited for increasing autumn germinator's population and allowing them to succumb to frost injury in severe winters. Thus, the objective of this research was to determine the most effective doses of cyanamide for inducing germination of *Papaver dubium*, which will help in devising strategies to reduce its soil seed bank density and further spread.

METHODOLOGY

The effect of five concentrations of cyanamide (1, 5, 10, 20 and 30 ppm) along with control were examined at temperatures ranging from 5-20^{o}C in the dark. Four seed accessions of *Papaver dubium*, collected from the same location/site during 2008 to 2011, were used and stored at room temperature. For each treatment, three replications were used. In petri dishes (5 cm diameter) with filter paper, 50 seeds were treated either with 15 ml deionized water or 15 ml treatment solution. Germination data was recorded from one to four weeks after treatment.

RESULTS

Result showed that maximum germination was induced by a conc. 1ppm cyanamide, followed by 5 ppm at different temperatures (5-20^{o}C) tested. In addition, germination percentage for each year seed accessions differed and highest germination was observed for seed accession of 2009 (50%), followed by 2008 (40%), 2010 (6%) and 2011 (4%), respectively. Over all, maximum seed germination was observed in temperature range of 10^{o}C to 20^{o}C, which correspond to the natural conditions prevailing outside and facilitating to bloom *Papaver*.

CONCLUSION

Based on the results, it is recommended to use 1.0 ppm cyanamide to induce seed germination of *Papaver dubium* in autumn and rendering the seedling to be perished in severe winter prior to seed setting in spring. This strategy would aid in lowering the seed bank in the soil and further spread in Japan.

Effectiveness of arbuscular mycorrhizal fungi against *Striga* emergence in sugarcane and sorghum

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Sugarcane is an important commercial crop of Karnataka occupying around 4313.6 hectares of land with an average cane productivity of 98 t/ha. Similarly, Sorghum is considered as one of the major food grain crops of Karnataka being cultivated over 18.02 lakh ha. However these two major crops of northern Karnataka are overwhelmed by the infestation of *Striga*, which is estimated to cause around 12-72% reduction in yield depending upon the severity of infestation. There are several options available for the management of *Striga, viz*. using resistant varieties, cultural manipulation and sequential application of herbicides. Among them, *Striga* management by using herbicides is most effective but at the same time they are toxic and persist in the soil for a considerable period of time and may bring about changes in the soil biological properties. In order to prevent the weed menace as well as to prevent the environmental pollution by herbicides, the biotic interaction is required for effective and sustainable management of weed infestation and one such biotic interaction that could be the mutualistic interaction between AM fungi with the roots of several plants. Our preliminary studies have clearly indicated that AMF colonization correlated with lower induction of germination of *Striga* emergence.

METHODOLOGY

A pot experiment study was undertaken at University of Agricultural Sciences, Dharwad during 2013 and 2014 to assess the effectiveness of arbuscular mycorrhiza fungal (AMF) inoculation on the suppression of *Striga* in sugarcane and sorghum system. The experiment was laid out in a completely randomised design with four replications. Treatments comprising of the standard AMF strains, *viz*. T_1: *Gigaspora margarita* T_2: *Acaulospora laevis*; T_3 : *Glomus macrocarpum*; T_4: AMF consortium comprising of all three AM fungal strains; and T_5: without AMF inoculation . The pots were filled with *Striga* infested soil followed by mixing of AMF inoculum as per the treatment schedule before planting and sowing of sugarcane and sorghum respectively. The plants were grown under conducive environment for four months and were watered twice a weak with distilled water and Hoagland's nutrient solution. The data on the emergence of *Striga,* AM fungal spore count, percent root infection, plant height and dry matter and chlorophyll content were recorded in both sugarcane and sorghum.

RESULTS

Results (Table 1) revealed that AMF inoculation inhibited *Striga* emergence significantly in both sugarcane and sorghum. However, application of AMF as consortium suppressed the *Striga* emergence to a greater extent compared to individual strains of AMF. The highest number of *Striga* emergence was observed in the pots received without AMF inoculation (5.63 and 5.80 sugarcane and sorghum respectively). With respect to the mycorrhizal parameters, *viz*. root colonization and spore count was highest in the sugarcane plants inoculated with AMF consortium *(*93.5% and 766.5 spore cont /50g of soil respectively). Similarly, sugarcane plants received AMF consortium recorded the highest plant height, total dry matter and chlorophyll content (34.7 cm, 19.0 g/plant and 49.0 respectively). Similar trend was also observed in the sorghum due to the application of AMF as consortium over single application of AMF strains.

Table 1. Effects of arbuscular mycorrhizal fungi on *Striga* emergence, AMF root colonization, AMF spore count, plant height, plant dry matter and chlorophyll content of sorghum and sugarcane

Treatment	Sugarcane						Sorghum					
	Number of *Striga* emergence	Per cent Root Colonization	AMF spore count/50 g soil	Plant height (cm)	Plant dry matter (g)	Chlorophyll content	Number of *Striga* emergence	Root Colonization (%)	AMF spore count/50 g soil	Plant height (cm)	Plant dry matter (g)	Chlorophyll content
Gigaspora margarita	1.90	61.0	533.2	28.6	12.0	43.0	1.00	72.5	505.3	147.0	55.0	45.0
Acaulospora laevis	0.00	68.7	544.0	33.1	15.0	42.3	0.00	69.6	546.0	139.0	40.6	44.3
Glomus macrocarpmum	0.00	87.5	560.7	32.1	18.0	45.5	0.00	87.5	578.8	159.7	60.8	46.5
AMF Consortium	0.00	93.5	766.5	34.7	19.0	49.0	0.00	90.0	752.1	163.0	74.2	48.0
Without AMF inoculation	5.63	47.7	130.0	25.7	10.0	40.0	5.80	42.5	108.2	122.5	30.0	41.0
LSD (P=0.05)	1.78	7.88	64.3	15.14	0.56	0.28	1.78	5.32	42.7	26.64	0.56	0.28

CONCLUSION

The preliminary findings are indicative of the effectiveness of AMF in protecting both sorghum and sugarcane against *Striga*.

Applicability of borax and thiourea for management of *Orobanche*

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Broomrapes (*Orobanche)* are devastating parasitic weeds causing enormous losses in agriculture. The seeds of the parasites are very minute in size and remain viable in the soil for up to 20 years. Reduction of the weed seed bank has been suggested as an attractive option. Seeds germinate only when induced by the germination stimulants that are released by the host plants. Suicidal germination is an approach to apply stimulants before the crops to induce germination of seeds and the germinated seeds die due to lack of host plants. However, this method is very sensitive to several factors and hence often a failure at field levels. Recently we proposed a novel concept of decomposing the germination stimulants in soil prior to action by two commonly used compounds in agriculture, *viz.* borax and thiourea (quenching agents). In this study we have standardized the doses of the two compounds and demonstrated the actual suppression of the germination of seeds of parasitic weeds by applying borax and/or thiourea.

METODOLOGY

Phytotoxicity studies were performed by applying borax and thiourea (quenching agents) solutions of different molar concentrations and observing the phytotoxic effects by assigning a score with toxicity scale from 0-5, where '0' (no injury) and '5' (dead plants) at different dose and time periods after application. The preconditioned of *O. crenata* seeds were treated with Nijmegen-1 (synthetic germination stimulant) or subjected to host plant seedlings and followed by borax or thiourea solution after 24 or 48 h. The arrest of germination of *O. crenata* seeds was recorded.

RESULTS

Different concentrations of borax and thiourea were tested for phytotoxicity on tomato seedlings of 25 days old. Results from the phytotoxicity studies indicates that borax and thiourea were not causing any toxicity when applied at lesser doses upto 5mM, but when applied at higher dose, of 10 mM and more, they caused phytotoxicity on tomato. The plants showed chlorotic necrosis and yellowing in the margin of the leaves after 7 days of application (scale score 1), but the plants soon recovered with 10 mM. At 50 and 100 mM of the quenching agents, the plants were killed. The quenching agents were applied in two ways, **a.** tomato seedlings were treated with borax or thiourea before exposing them to preconditioned *O. crenata* seeds. **b.** First tomato seedlings were placed near the preconditioned seeds and then treated with quenching agent after 24 h. In both set-ups *O. crenata* seeds did not produce radicle or show any sign of germination, implying that both agents were able to stop or break the germination signal for the parasite (Table 1).

Table1. Effect of borax and/or thiourea on the germination of *O. crenata* seeds induced by tomato seedlings

Treatment	No of seeds germinated after days of application				
	10	20	30	40	50
Tomato seedlings in water	0 (0.71)[a]	15.33(3.97)[a]	21.33(4.67)[a]	31.66(5.67)[a]	34.66(5.93)[a]
Borax + tomato seedlings after 24 h	0 (0.71)[a]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]
Thiourea (1 mM) + tomato seedlings after 24h	0 (0.71)[a]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)b
Tomato seedlings + borax (1 mM) (simultaneous)	0 (0.71)[a]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]
Tomato seedlings + thiourea (1 mM) (simultaneous)	0 (0.71)[a]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]	0 (0.71)[b]
Control (distilled water only)	0 (0.71)[a]	0 (0.71)[b]	0 (0.71)b	0 (0.71)b	0 (0.71)[b]

The first number refers to the number of germinated seeds. Values in parentheses are the transformed values. Values with the same superscript letter are not significantly different from each other (0.05% level of probability).

CONCLUSION

When the stimulant Nijmegen-1 and borax/thiourea (1 mM) were applied simultaneously, no germination was observed either. Thus effective quenching of the stimulant can be achieved at a concentration level of 1 mM. This effective concentration is much lower than the critical range of 5 mM for any phytotoxic effect. Both Borax and thiourea are inexpensive and eco-friendly salt, commonly used in agriculture. Borax is used as a micronutrient and thiourea is used in agriculture for plant growth stimulation. However, prolonged use of these chemicals may result in undesirable soil toxicity and consequently phytotoxicity on the crops.

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Management of *Striga* scourge in sugarcane – Lessons from strategic participatory research

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Striga asiatica is a parasitic weed which seriously constrains the productivity of sorghum, maize, upland rice, millets and sugarcane. Sugarcane is the most preferred host for *Striga* among these crops. Its incidence is severe in major cane growing districts of North Karnataka (Belagavi, Bagalkot and Vijayapur), as the traditional sorghum/maize growing areas have been brought under cane cultivation. The problem was not serious previously with sorghum and maize, but it is serious in nature in sugarcane due to its longer duration which encourages repeated flushes of *Striga* causing heavy crop damage. The weed survives by siphoning off water and nutrients. It totally depends on its host crop for its own growth and development in its early part of life cycle till it emerges out from the ground. The present infestation level is so high, the farmers of this region are fighting a loosing battle in saving their crop. There is decline in the cane yield to the extent of 20-70%, sometimes total crop failure also, threatening cane cultivation. Yet, farmers are not ready to give up sugarcane crop, as it is more remunerative. Unfortunately, *Striga* infestation continues to extend to new areas also, which is of great concern.

METHODOLOGY

Field surveys and pot culture studies were conducted to know the extent of *Striga* incidence, to determine the number of days taken for its emergence and to quantify *Striga* seed bank in the soil collected from problematic areas. The field trials were initiated on participatory approach in *Belagavi* district in severely infested sugarcane fields based on seed bank studies. Field surveys and pot culture studies indicated that *Striga* emergence was noticed after 110-120 days after cane planting (DAP). Based on this information, time of application of herbicide was decided in the trials. In the first trial, herbicides/herbicide mixtures were used as over top application at 110 and 150 DAP on emerged *Striga*. In the second trial, the herbicides/herbicide mixtures were applied at 90 DAP before the emergence of *Striga*, synchronising haustoria formation, with two methods of application, *viz.* surface application and deep placement in the furrows opened on either side of sugarcane rows.

Table 1. Influence of *Striga* management treatments on its density and dry weight in sugarcane in trials conducted on participatory approach

Treatment	1st trial		2nd trial		
	Striga density (no./m^2) 140 DAP	*Striga* density (no./m^2) 180 DAP	*Striga* density (no./m^2) 180 DAP	dry weight (g/0.5m^2) 180 DAP	Cane yield (t/ha)
Surface application of herbicides					
2,4-D 2 kg/ha	-	-	50.0	29.23	64
Atrazine 1.25 kg/ha	-	-	48.0	27.25	69
Diuron 1.5 kg/ha	-	-	45.0	24.28	77
Oxyfluorfen 250 g/ha	-	-	44.0	23.93	79
Metribuzin 1 kg/ha	-	-	49.0	27.80	66
Atrazine 1.5 kg/ha+ 2,4-D (2kg/ha)*	6	5	40.0	21.23	86
Diuron 0.75 kg/ha + 2,4-D (2kg/ha)*	4	3	38.0	20.52	93
Oxyfluorfen (125g/ha)+ 2,4-D (2kg/ha)*	3	3	37.0	19.80	95
Metribuzin 1 kg/ha+2,4-D (2kg/ha)*	4	4	41.0	21.56	85
Deep placement of herbicides					
2,4-D 2 kg/ha	-	-	34.0	18.87	96
Atrazine 1.25 kg/ha	-	-	12.0	2.10	101
Diuron 1.5 kg/ha	-	-	10.0	1.98	107
Oxyfluorfen 250 g/ha	-	-	7.0	1.43	111
Metribuzin 1.0 kg/ha	-	-	11.0	2.0	99
Atrazine 0.62 kg/ha + 2,4-D (1.0 kg/ha)	-	-	10.0	1.99	127
Diuron 0.75 kg/ha + 2,4-D (1.0 kg/ha)	-	-	8.0	1.47	134
Oxyfluorfen (125 g/ha) + 2,4-D (1.0 kg/ha)	-	-	5.0	0.42	136
Metribuzin 0.5 kg/ha + 2,4-D (1.0 kg/ha)	-	-	9.0	1.49	123
Weedy check	-	-	60	34.86	34
Farmers' practice (atrazine 1kg/ha *fb* 2,4-D 2.5 kg/ha) and inter-cultivations	-	-	55	32.40	39

*In the second trial, herbicides (in herbicide mixtures) were used at their 50% dose; $C_1$and C_2 were control plots against which method of different herbicide/herbicide mixtures were evaluated.

RESULTS

In the first trial, the herbicide mixtures applied on emerged *Striga* after 110-120 DAP was effective on *Striga* control (Table 1). In the second trial, herbicide mixtures or their single application were equally effective in controlling *Striga* when applied in furrows at 90 DAP than when applied as surface application. Oxyfluorfen 250 g/ha was more effective. A series of baby trials involving only promising treatments were conducted on farmers' fields to promote this technology which would save sugarcane crop from *Striga*.

CONCLUSION

Deep placementof oxyfluorfen 250 g/ha into the furrows at 90 DAP is very effective in reducing *Striga* seed bank, while surface application of herbicide mixtures at 110-150 DAP after emergence of *Striga* prevents further enrichment of *Striga* seed bank, as the parasitic weed is controlled before flowering.

Biological management of *Orobanche crenata* on tomato using native fungi and their metabolites

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Orobanche (broomrapes) are total root parasitic angiosperms attacking many economically important plants worldwide. It is a major production constraint in tobacco, tomato, mustard and brinjal in India with the losses ranging from 20-80%. Despite several strategies available for the management, no effective control has been achieved so far and thus integrated management using all the available options would be a better strategy. Bio-control using fungi and their crude metabolite extracts would serve as an important component in integrated management strategy. The current work explains the management of *O. crenata* in tomato by treatments with the native microbes and their metabolites isolated from the rhizosphere soil. Results indicated that *Penicillium oxalicum*, *Fusarium* sp. And their metabolite extracts were able to suppress the germination and delay the emergence *O. crenata.*.

METHODOLOGY

The fungi were isolated from the native rhizosphere of tomato infested with *O. crenata* from the farmers' fields near Gwalior and Jabalpur. Spore suspension (25 x 10^3 cfu/ml) was prepared by grinding 7 days old fungal mat along with the broth. Metabolite extracts were prepared from15 days old potato dextrose (PD) broth culture fungal mat was filtered and suspension was used for solvent extraction process. Several polar and nonpolar solvents were tried and ethyl acetate was found most appropriate for extracting the crude extracts of the fungi. Pot experiments were conducted in containment chamber during 2014-15 and the fungi were applied as seed treatments followed by foliar spray at 30 and 60 DAS on tomato (*Pusa Ruby*) with 3 replications per treatment. Observations on the emergence of *O. crenata* stalks, number of stalk per pots and growth of the plants were recorded (data not shown).

RESULTS

Results indicated that application of spore suspension and crude metabolite extract of *P. oxalicum* as seed treatment followed by foliar application caused a significant reduction in the stalk emergence of *O. crenata*when compared to the control. Neem cake slurry delayed the emergence of the stalks but at 150 days of observation, the emergence was near to the metabolite extract of *F.oxysporum* DWSR1 (Table 1).

CONCLUSION

The fungi when applied as seed treatment was able to produce a film of mycelial growth on the initial roots of tomato. This might alter the volatiles being released by the host roots and delay the preconditioning of the dormant seeds of *O. crenata* which reduces their germination and development (Musselman 1980). The foliar application of the fungal bio-agents enhances activity of defense and other enzymes related to signal transduction processes in the host plants (Goldwasser *et al.* 1999). The reduction in emergence of the flowering stalks would reduce the development of the parasite and thus the host crop may escape the infection during its critical stages and stalk emergence means less seed production and seed bank in the soil.

Table 1. Effect of microbes and crude extract on emergence of *O. crenata* stalks in tomato

Treatment	No. of *O. crenata* stalk (DAS)			
Seeds treatment *fb* soil drenching at 25 and 50 DAS	60	90	120	150
Neem cake slurry	0.00	8.33	30.3	42.6
F. oxysporum DWSR I crude extract	0.67	17.6	35.3	45.3
F. oxysporum DWSR II	3.33	23.3	41.33	47.6
Ridomil	2.00	13.0	38.3	50.0
F. oxysporum DWSR II crude extract	1.33	18.3	37.3	51.6
P. oxalicum DWSR I	4.00	7.33	9.33	12.6
F. oxysporum DWSR I	1.00	11.6	25.0	35.3
P. oxalicum DWSR I crude extract	1.67	14.6	22.3	32.6
O. crenata + tomato	5.67	41.6	50.0	66.0
Tomato alone	0.00	0.00	0.00	0.00
LSD (P=0.05)	1.91	3.52	4.03	2.04

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Eradication of quarantine weed, *Ambrosia psilostachya*

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Perennial Ragweed, *Ambrosia psilostachya* DC (Family: Asteraceae) is an invasive weed of quarantine importance to India and was detected in Turuvekere taluk, Tumkur district, Karnataka, India (Ramachandra Prasad *et al*. 2012). This weed is native of northern America (USA, Canada, Mexico) and has the history of spread to South America, Europe, Asia (Kazakhstan, Russia, Taiwan, Japan), Africa (Mauritius) and Australia (Eardley 1944, Auld and Medd, 1987). The weed being invasive, affects bio-diversity and it also interferes with animal husbandry activities. The pollens of the weed pose risk to human health by causing allergies and hay fever. The Government of India has taken lead to eradicate this alien weed through National Institute of Plant Health Management, Department of Agriculture & Cooperation, Hyderabad. The eradication efforts were initiated from July 2013. The weed spread was delimited (Sathyanarayana *et. al*. 2014) and a project was formulated with a lead role of NIPHM in association with stake-holding organisations, *viz*. Directorate of PPQS, Karnataka State Agriculture Department, University of Agriculture Sciences, Bangalore and Weed Science Research Institute, Jabalpur. A similar attempt was successfully made by limiting the infestation of *A. psilostachya* to 1160 ha in Russia (Moskalenko 2001).

METHODOLOGY

A project plan was prepared for effective eradication of *Ambrosia psilostachya* and following methodology was adopted for the same.

1. Delimiting the area of invasion and creation of buffer zone: The weed detection was systematically gauged and mapped using various techniques ranging from awareness creation and passive reports, active surveillance and use of GPS. The delimiting surveillance mapped the exact spread of the weed. It was found that the weed has spread to an area of about 400 acres in between the coordinates, N 13.11189° to 13.18656° and E 76.40759° to 76.42426° in Turvekere taluk (Sathyanarayana *et al*. 2014).

2. Awareness creation and capacity building: Wide spread awareness was created in order to stop the spread of the weed outside the delimited zone and buffer area. This was achieved by intensive door to door campaign, wall posters, wall paintings, distribution of pamphlets in local language, sensitization of stake-holding organizations by way of holding joint meetings and workshops, conduct of training programmes and Filed Days and regular visits to the area concerned.

3. Stakeholder sensitization, consultations and involvement: NIPHM under its aegis organised workshops and meeting and sensitized the stake holding organizations i.e. Karnataka State Department/s of Forests, Irrigation, Animal Husbandry, Horticulture, Revenue, Local Self Governments & Banks and the collaborating partners *viz*. Weed Science research Institute, Jabalpur, Department of Agriculture, Karnataka, University of Agricultural Sciences, Bangalore and Directorate of Plant Protection, Quarantine & Storage, Faridabad. Further, the role of collaborating organizations was identified and agreed upon by the concerned stakeholders to facilitate the systematic and concerted eradication efforts. The print and electronic media were also put to use to create wide spread awareness.

The farmers of the affected area *i.e*. Turvekere Taluk in Tumkur District of Karnataka, India were encouraged to form an association so as to involve them as Local Partners. The association was formed and named as "Ambrosia affected Farmers' Welfare Association, Muniyur". The Local Partners are doing well beyond the expectations and are actively involved in spreading the awareness by wall posters, door-to door campaign, distribution of pamphlets and also the actual control operations including monitoring the eradication efforts at micro-level.

4. Stopping the spread of the weed to new areas: It was observed that primary reason for the spread of the weed in affected area was of passive nature. The seeds of the weed are not viable under local conditions. The practice of plantation farmers to transport soil from forest and/or public lands where the weed was present has helped the weed in spreading its tentacles to nearby villages. The use of manure where the weed was found present in the mother pit also caused havoc. The use of tractors, agricultural implements etc. also aided the weed spread to newer areas. The weed being propagated by runners, even a fraction of the root if transferred to a new area would germinate to produce shoots. The cultivation practices, mechanical weeding, uprooting and all such unmindful of activities had led to the spread of the weed.

To curb the spread, therefore, a ban was imposed on transport of soil from affected area. To legalise the ban, recommendations have been made to the Government of India & Government of Karnataka for notifying and promulgating respectively, the area as under domestic quarantine. Meanwhile extensive awareness creation and the vigilance of Local Partners has helped to stop the further spread of the weed. The sensitization of farmers on use of agriculture equipments was also undertaken.

5. Control Operations: The periodical chemical sprays were employed using herbicides, glyphosate at 2.05 kg/ha and 2,4-D sodium salt 80 WP at 1.0 kg/ha in cropped lands, bunds, plantations, roadsides, public places, manure pits, forest, revenue lands and irrigation channels. Most of the affected area has come under at least three numbers of sprays. As the weed propagation is by runners (runner stretch even to a length of 1 m), the spraying of herbicides gave only a top kill for certain period of time and new sprouts emerged due to rains or irrigations after 2-3 months. The repeated sprays are therefore continued in affected area. The intensive spraying has reduced the weed density to some extent. Further, it was observed that a local strain of a fungus was naturally killing the stems of this weed. Hence, the fungus was isolated and was found to be *Phoma* spp. The fungus is now mass multiplied and sprayed on targeted weed coverage to aid the eradication efforts.

6. Surveillance: The systematic surveillance efforts are planned and executed by surveys, monitoring, random filed visits, interviews and enquiries to ensure that the weed is not spread to other areas and that the control operations are on track. The data on efficiency of spraying is being recorded at pre-selected locations at regular intervals and at periodical pre and post spraying stages and the photographic evidences are being gathered on the weed suppression and habitat regeneration.

RESULTS

The extensive awareness creation, stakeholder sensitization and intensive herbicide sprays have resulted in stopping the weed spread to new areas and in suppressing the weed population in infested areas. The degree of suppression however varies at present depending upon the type of area affected, farming practices and spraying efficiency. The weed density is gradually decreasing, indicating the success of the programme. The weed suppression can also be gauged from the fact that the replaced weed flora is re-emerging in habitats once completely replaced by *Ambrosia psilostachya*. The prominent re-appearance being *Hyptis suaveolens* (L.) Poit., *Borreria stricta* (L.F.) DC., *Ageratum conyzoides* L., *Physalis minima* L., *Sida acuta* Burm. f., *Tridax procumbens* L., *Digitaria sanguinalis* (L.) Scop., *Dinebra retroflexa* (Vahl) Panzer, and *Cynodon dactylon* (L.) Pers. The details of the spraying locations and weed suppression are provided in Table 1.

Table 1. Spray locations and reduction in weed density

Name of the village	No. of farmers	Percent infestation	Area infested and sprayed (ha)	Number of periodical sprays with herbicides	% reduction in the density of the weed
Muniyur	69	25 – 100	43.3	4	50
M. Bevinahally	8	50 – 100	7.6	6	75
Srirampura & Gottikere	41	50 – 100	19.2	3	30
Madihally	37	50 – 100	17.5	6	60
Aralikere	19	25 – 100	4.0	4	40
Arisinadahally	15	50 – 100	5.0	3	50
Dwaranahally	4	25 – 100	2.0	3	60
Pura	1	05	0.5	3	75
Chendur	1	05	0.1	3	75
Public land	NA	25– 100	40.0	3	50 – 75
Total	195	05– 100	99.2	3-6	30 – 75

CONCLUSION

Ambrosia psilostachya is an invasive weed of quarantine importance to India and the invasion of this weed appears to be in control and amenable to eradication. A delimiting survey showed spread of the weed between N 13.11189° to 13.18656° and E 76.40759° to 76.42426° in Turuvekere area of Karnataka. The weed has been eradicated in some small and isolated infested patches due to awareness programme, which has prevented further spread. However, the complete eradication can be achieved in all infested areas in about 3-4 years. The co-ordination and cooperation of all stakeholders will help in reducing the time frame for complete eradication of the weed.

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Control of hemiparasite, *Dendrophthoe falcata* on tree crops

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Control of hemi parasitic weed**,** *Dendrophthoe falcata* is difficult as it grows on tall branches of trees. Most promising chemical reported for the control of the parasite was ethephon (Hawksworth and Johnson 1989). Ethephon releases ethylene, a gaseous hormone in plants. Ethylene in high concentrations acts as a defoliant. A trial was initiated to test the efficacy of ethephonfor the control of *D. falcate,* member of Loranthaceae family commonly seen in the tropics.

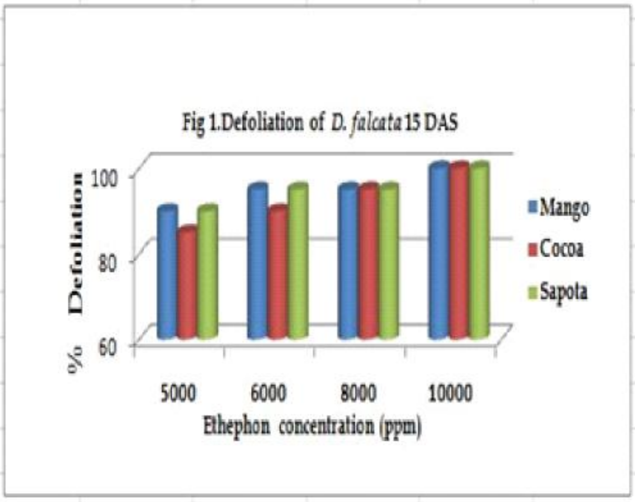
METHODOLOGY

The study was conducted in the College of Horticulture, Thrissur, Kerala, India during 2010 to 2013. Mango, sapota and cocoa trees infested with *Dendrophthoe falcata* were sprayed with different concentrations of ethephon. Treatments included were T1 – 5000 ppm, T2- 6000 ppm, T3- 8000 ppm, and T4- 10,000 ppm. The chemical was sprayed on the parasite with a knapsack sprayer so as to completely wet the plant. Observations on defoliation and regrowth was taken by visual scoring and expressed in percent. Observations were recorded on the 15th day. The regrowth of the parasite was monitored at monthly intervals upto six months. Based on the number of pointswith regrowth, a scoring pattern was developed and expressed in percent.

RESULTS AND DISCUSSION

Study showed that application of ethephon in all the four concentrations was effective in defoliating the parasite. The percent of defoliation varied with the host and concentration of the chemical. The rate of defoliation was faster in mango as compared to sapotaand cocoa. Ethephon at 10,000 ppm gave best results in complete defoliation of the parasite in all the host plants. Regrowth of the parasite depended on the dose of the chemical and the host species. The highest regrowth was observed at lower concentrations.-Specify the doses

Application 10,000 ppm of ethephon gave the best result even after 6 months. Among the hosts, regrowth rate was higher for mango as compared to cocoa and sapota.



CONCLUSION

Directed spraying of ethephon at 8000 to 10,000 ppm defoliated the parasite completely in host plants - mango, cocoa and sapota without regrowth for at least 6 months. However, it depended on the host species and also the season of application. The hormone was safe to the host plant.

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Management of *Cyperus rotundus* in soybean

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Weeds including *Cyperus rotundus* L. (purple nutsedge) cause considerable yield losses in soybean [*Glycine max* (L.) Merrill]. Continuous use of pre- and/or post-emergence herbicides in soybean for last several years has resulted in preponderance of *C. rotundus*, which is hardly controlled by the conventional selective herbicides. *C. rotundus* is a perennial invasive weed, aggressive colonizer, and grows consistently up to maturity of soybean (Kumar *et. al.* 2012). In the changing climate, it may pose more interference with soybean due to its higher water-use efficiency, greater leaf area, root length and dry weight, and greater numbers of tubers in response to elevated CO_2 level (Rogers *et. al.* 2008). Therefore, interference effect of weeds/*Cyperus*, economic threshold (ET) and the possible weed/*Cyperus* management options using dormancy breakers and tank-mix herbicides were investigated in these experiments.

METHODOLOGY

Experiments were carried outat the Division of Agronomy, Indian Agricultural Research Institute, New Delhi for six years during 2007-2012 to evaluate interference effects of weeds/*Cyperus vis-à-vis* weed control efficacy of several management options (tillage, herbicide tank-mixes, dormancy breakers, soil solarization *etc*.) on the growth and yield of soybean (Cv. *Pusa 20*). Soil was alluvium (Typic Ustochrepts; Order Inceptisol) in origin and sandy-loam with 0.54% organic C and pH 7.7. Soil available P (17.5 kg/ha) and K (180.1 kg/ha) were medium, but available N (260.5 kg/ha) was low. The experiments were laid out in a randomized block design or split plot design (as applicable) with three replications.

RESULTS

In the first experiment, it was observed that the 'natural weed infestation including (UWC) and excluding *C. rotundus* (UWC-Cyp)' and the treatment of 200 *Cyperus rotundus* plants/m^2 caused greater reductions in soybean yields and were most competitive. The economic threshold (ET) level of *C. rotundus* in soybean was 19-22 plants/m^2. Yield losses caused by the ET ranged between 9.1 and 11.5%, which are economic loss under this situation. In the second experiment, the control of *C.rotundus* was envisaged and found that *Cyperus* control was more in the tank-mixes of pendimethalin (0.75 kg/ha) and imazethapyr (0.1 kg/ha) PE with GA_3 (400 ppm), and KNO_3 (6%) compared to their respective sequential applications. These two tank-mixes in terms of total weed control or weed control efficiency were much superior to other treatments. In the third experiment, zero tillage (ZT) resulted in significantly lower weed density/m^2 than conventional tillage (CT), but weed dry weight, soybean plant height, leaf area index and yield were comparable between the tillage treatments. Among weed control/ herbicide treatments, tank-mix application of pendimethalin 0.5 kg/ha + imazethapyr 0.075 kg/ha resulted in lower weed density and dry weight and higher soybean yield than other weed control treatments.

CONCLUSION

ET of *C. rotundus* in soybean was 19-22 plants/m^2. The yield losses caused by the ET ranged between 9.1 and 11.5%. Zero tillage combined with tank-mix pre-emergence application of pendimethalin 0.5 kg/ha + imazethapyr 0.075 kg/ha results in better weed control and higher soybean yield. Again, pre-emergence application of GA_3 (400 ppm) or KNO_3 (6%) with this combination was equally beneficial for effective control of weeds including *C. rotundus* in soybean.

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Herbicide resistant weeds and their management in wheat

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Herbicide resistance in weeds is a global problem (Heap 2015). In India, the first case of herbicide resistance was of Littleseed canarygrass (*Phalaris minor* Retz.). This is the most troublesome wheat weed and has evolved multiple herbicide resistance (Chhokar and Sharma 2008). A few farmers in northern India having infestation of multiple herbicide resistant populations are facing significant wheat yield reductions in the absence of effective alternative herbicides. Recently the populations of two other weeds namely, Rabbit foot grass (*Polypogon monspeliensis* (Linn.) Desf.) and Toothed dock *(Rumex dentatus* Linn.), have started defying control with sulfonylurea herbicides. The increased cases of herbicide resistant weeds are a threat to wheat production and productivity. Therefore, alternative herbicides should be identified and integrated with non-chemical methods for effective herbicide resistance management.

METHODOLOGY

Herbicide resistance profile of *Phalaris minor, Polypogon monspeliensis* and *Rumex dentatus* populations was studied for three *Rabi* seasons of 2012-13 to 214-15. Weed populations were collected from fields having uncontrolled history with different herbicide usage. Through bioassay, quantification of herbicide resistance profile in pots was carried out. The various herbicides (Table 1) were used for the resistance profile study. Based on the fresh biomass reduction, the 50% growth reduction (GR_{50}) values were determined, based <16>on which effective herbicides were identified.

RESULTS

The quantification and characterization of herbicide resistance in weeds revealed that *P. minor* has evolved multiple herbicide resistance to three modes of action (photosynthesis at photosystem II site A, ACCase and ALS inhibitor). Some of the populations had GR_{50}values for clodinafop more than 20 times greater than that of the most S (susceptible) population. Population having high level of resistance against clodinafop exhibited cross-resistance to fenoxaprop (fop group), tralkoxydim (dim group) and pinoxaden (den group). Similarly, population resistant to sulfosulfuron showed cross-resistance to mesosulfuron and pyroxsulam. The *P. minor* populations resistant to six groups (phenylurea, sulfonylurea, aryloxyphenoxypropionic, cyclohexene oxime, phenylpyrazole and triazolopyrimidine sulfonamide) were sensitive to flufenacet, pyroxasulfone, metribuzin, terbutryn, and pendimethalin. Also, the multiple herbicide resistant populations showed sensitivity to, glyphosate and paraquat. *P. monspeliensis* has shown resistance to ALS inhibitor herbicides (sulfosulfuron, mesosulfuron and pyroxsulam). Both these herbicide resistant grass weeds are susceptible to pyroxasulfone and flufenacet. Toothed dock (*Rumex dentatus*), a broadleaved weed has also evolved resistance to ALS inhibitor herbicides (metsulfuron, iodosulfuron, florasulam and pyroxsulam) but was sensitive to 2,4-D, carfentrazone, metribuzin, pendimethalin and isoproturon. The evolution of herbicide resistance in multiple weeds is an emerging threat to wheat in Indo-Gangetic Plains. Some of the farmers having infestation of herbicide resistant weed populations are facing significant yield reductions due to lack of knowledge as well as unavailability of effective alternative post-emergence herbicides. If the problem of resistance is not tackled, it may lead to serious consequence of decrease in wheat production. The yield reductions due to herbicide resistant multiple weed populations can be restricted with pre-seeding application of glyphosate or paraquat in combination with pendimethalin or terbutryn in no-till wheat. As the introduction of new herbicide chemistry has slowed down, concerted efforts are required to extend the effective use of the available herbicides. The long-term effective resistance management plans should comprise the integration of chemical and non-chemical means of weed management along with knowledge of weed biology.

Table 1. Herbicide resistant weeds in India and their control

Weed	Resistance	Susceptible
Littleseed canarygrass (*Phalaris minor)*	Phenyl urea (Isoproturon), Sulfonylurea (sulfosulfuron, mesosulfuron), Aryloxyphenoxypropionic (Clodinafop), Cyclohexene oxime (Tralkoxydim), Phenylpyrazole (pinoxaden) and Triazolopyrimidine sulfonamide (pyroxsulam)	Pendimethalin, Metribuzin, Terbutryn, Flufenacet, and pyroxasulfone
Rabbitfoot grass (*Polypogonmonspeliensis*)	Sulfonylurea (sulfosulfuron, mesosulfuron), Triazolopyrimidine sulfonamide (pyroxsulam)	Pendimethalin, Metribuzin Clodinafop, Fenoxaprop, Pinoxaden, Flufenacet andPyroxasulfone
Toothed dock (*Rumexdentatus*)	Sulfonylurea (metsulffuron, triasulfuron, iodosulfuron), Triazolopyrimidine sulfonamide (pyroxsulam, florasulam)	2,4-D, Carfentrazone, Pendimethalin, Metribuzin& Terbutryn

CONCLUSION

The increasing number of herbicide resistant weeds and multiple herbicide resistance in weed are major threats to wheat production. Integrated weed management strategies must be developed to prevent the spread of herbicide resistant weeds and extension of resistance to new chemicals by using alternative herbicides supplemented with non-chemical methods of weed management.

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Technical Session 12

Tillage, nutrients, seeding time, soil and water in relation to weed management in Asia-Pacific region

Conservation agriculture-based practices reduced weed problems in wheat and caused shifts in weed seedbank community in rice-wheat cropping systems

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In rice-wheat cropping systems of northwest India, there is increased interest in conservation agriculture (CA) - based practices including zero-tillage and residue retention and in diversifying rainy season rice crop with maize to address issues of rising scarcity of labor, water, and energy, and climate change. Weeds are considered major constraints to wider adoption of CA practices and dependence on herbicides has increased in these new systems for weed control. Greater dependence on herbicides can lead to both environmental (e.g. herbicide resistance in weeds and contamination of water resources) and human health risks. In the region, *Phalaris minor*, the most troublesome weed of wheat has already developed cross to multiple resistances to most commonly available herbicides in the region. These issues warrant the need to developand integrate non-chemical approaches for sustainable weed control so that dependence on herbicides can be reduced and risks of herbicide resistance be minimized. The objectives of this study were to evaluate the long-term effects of CA-based practices on the density and composition of the weed seedbank and to assess the potential importance of weed seed predation in mediating seedbank changes.

METHODOLOGY

A long-term field study was conducted at CSISA Experimental Research Platform located at Central Soil Salinity Research Institute, Karnal, India. Four cropping systems were included: S1) Conventional rice-wheat system (puddle-transplanted rice and tilled wheat) ; S2) Partial CA-based system (rice-wheat-mungbean rotation with puddled transplanted rice and CA-practices for other crops); S3) CA-based rice-wheat-mungbean system (same as system 2, but with direct sown, zero-till rice); and S4) CA-based maize-wheat-mungbean system (same as system 3, but with zero-till maize instead of rice). In CA-based systems, crops were grown under zero-till with 100% residue retention on the soil surface. To assess the effects of CA-based practices on the weed seedbank, soil samples were collected from 0-10 cm depth after four cropping cycles and the germinable seedbank was estimated through exhaustive germination under common controlled conditions.To quantify the effects of CA-based practices on weed seed predation, 50 seeds of five wheat and five rice weed species were placed on the soil surface for one week during the fallow period between harvest and planting of the next crop. Predation rates were estimated by calculating the percentage of seeds that disappeared during that time.

RESULTS

After four years, the seedbank of the *Rabi* season (winter/dry) weeds *Phalaris minor, Rumex dentatus, Melilotus indica, and Coronopus didymus* decreased by 90-100%, 75-100%, 70%, and 78%, respectively in CA-based systems (S2, S3 & S4), compared to the conventional till system (S1). Because emerged weeds were almost non-existent in wheat in CA systems (S2, S3 and S4), herbicides were not applied for weed control after three cropping cycles. For *Kharif* (rainy wet) season, the seedbank of aerobic species (e.g. *Bracharia* spp, *Dactyloctenium aegyptium*) in addition to *Echinochloa colona* increased in aerobic rice or maize based systems (S3 & S4) compared to anaerobic systems (S1 & S2). In contrast, the seedbank of *Ammania*, *Alternanthera sessilis*, *Lindernia* spp increased in puddle (S1 & S2) compared to non-puddled (S3 & S4) systems. The seedbank of *Cyperus iria*, *Eragrostis japonica* and *Leptochloa chinensis* did not differ among treatments. Seed predation of *P. minor*, a major weed of wheat was higher in CA-based compared to conventional systems. Similarly, seed predation of rice weed species including *E. crus-galli* and *Caesulia auxillaris* was higher in CA-based systems than in conventional systems but seed predation of *Eclipta* and *Corchorus olitorius* did not differ.

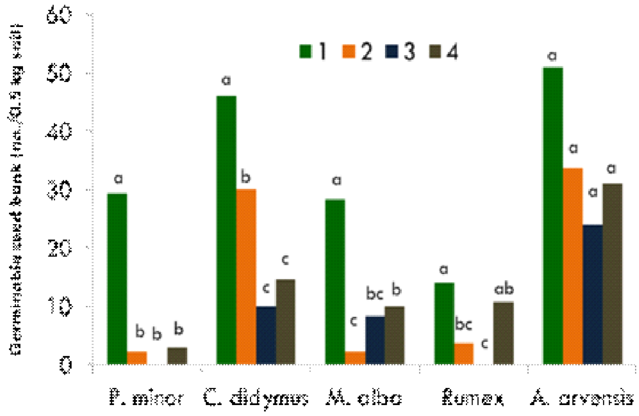

Fig. 1. Germinable seedbank of wheat weed species after four continuous cropping system treatments with varying level of CA-based practices. Within species, bars with similar letters are not statistically different at the 0.05 level of significance using Fischer Protected t-test.

CONCLUSION

Results suggest that CA can play an important role in reducing herbicide use in wheat and in managing herbicide-resistant populations of *P. minor*. Since seed predation appears to play an important role in regulating certain weed species in CA-systems, greater understanding of management practices which enhance predation (e.g. bund habitat management) may be useful for designing more effective integrated weed management programs to address on-going weed management challenges in CA-rice.

Tillage and weed management for improving productivity and nutrient uptake of soybean

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Soybean [*Glycine max* (L.) Merr.] has emerged as a potential crop and brought about perceptible change in the economy of the farmers in central India. Weeds are a major constraint and their control is essential for successful crop production. Hand-weeding is a traditional and effective method of weed control, but untimely continuous rains and unavailability of labour at peak time are main limitations of manual weeding. The only alternative that needs to be explored is the use of post-emergence herbicides. Further, herbicide mixtures may broaden the window of weed management by broad-spectrum weed control (Bineet *et al.* 2001). An experiment was conducted to study the performance of soybean grown after wheat under varying tillage and weed control practices.

METHODOLOGY

The experiment was conducted during *Kharif* season 2008 at the research farm of Indian Agricultural Research Institute, New Delhi on sandy loam soil, slightly alkaline (pH 7.6), low in organic C (0.38%), and available N (145 kg/ha), medium in available P (9.01 kg/ha) and high in available K (259.4 kg/ha). The treatments included four tillage and crop establishment practices (conventional tillage flat-bed, conventional tillage raised-bed, zero tillage flat-bed and zero tillage raised-bed) and six weed management options, (control, weed free, pendimethalin at 0.75 kg/ha as pre-emergence (PE), chlorimuron-ethyl at 6 g/ha as post-emergence (POE) at 15 days after sowing (DAS), pendimethalin at 0.75 kg/ha as PE + 1 hand weeding (HW) at 25 days after sowing, pendimethalin at 0.75 kg/ha as PE + chlorimuron ethyl at 6.0 g/ha as POE at 15 DAS) laid out in a thrice replicated split-plot design, keeping tillage and crop establishment in main plots and weed management options in sub-plots. The gross plot size was 16.8 m^2 and net plot was 15 m^2. After the harvest of *Rabi* crop wheat in April, land preparation was done as per treatment and sowing was done on 10 July, 2008 using 'DS 9814' variety with a seed rate of 80 kg/ha, and a basal dose of 20, 60 and 40 kg N, P_2O_5 and K_2O /ha was applied. The sowing was done at a row to row spacing of 35 cm with the help of zero-till seed drill in flat-bed and 20 cm on the top of bed with the help of bed planter. The crop was harvested on 23 October, 2008.

RESULTS

Major weed flora observed were: *Echinochloa colona* (12.7%) among grasses; *Digera arvensis* (10.4%) among broad-leaved weeds; and *Cyperus rotundus* (62.5%) among sedges. Higher weed count was noticed under ZT due to no soil disturbance and simultaneous germination of weeds along with the crop (Table 1). Although paraquat was sprayed before sowing, which desiccated the foliage of all the previously growing weeds, but some of the over-grown weeds regenerated after two weeks. On other hand, all the weeds growing previously were killed due to tillage operation under CT, and emergence of new weeds was delayed compared with crop seedlings. Lower weed population in the bed-planted crop was due to closer row spacing on the bed. More foliage growth of the bed-planted crop also checked weed population in the furrows. There was significant difference in weed dry weight at 60 DAS due to tillage and crop establishment practices. It was comparatively more under ZT because of no-tilling of the soil compared with 3-4 ploughings given under CT. Although there was greater weed infestation in the furrows initially due to more space and better soil moisture condition, the weeds in furrows also got smothered with advancement of crop growth and development of canopy cover. On the other hand, flat-bed crop was sown at uniform spacing (35 cm) provided adequate and uniform inter-row space for the weeds to grow. Several workers reported decrease in weed infestation in furrow-planted compared with flat-sown crop (Behera *et al.* 2005, Mishra and Singh 2009).

Weed management practices brought about significant effect on weed growth. Presumably, the highest weed count was under unweeded control, which was decreased by more than half due to different treatments at all the stages of growth. Pre-emergence application of pendimethalin provided effective control of all species from early stages. Further, HW and post-emergence application of chlorimuron-ethyl at 15 DAS checked the emergence of the second flush of weeds. Both of these treatments, i.e. pendimethalin + HW and pendimethalin + chlorimuron-ethyl were equally effective and resulted in near weed-free conditions throughout the crop growth. The minor weeds emerging late in season did not cause significant adverse effect on crop growth. Pre-emergence application of pendimethalin, followed by post-emergence chlorimuron-ethyl was however slightly inferior to pendimethalin + HW. Application of pendimethalin or chlorimuron-ethyl alone was not much effective to control the weeds at initial stage and/or second flush in soybean, respectively.

Pre-emergence application of pendimethalin provided complete elimination of grassy weeds and most of the broad-leaved species. Second flush of the weeds was checked by HW or application of chlorimuron ethyl at 15 DAS. Thereafter, there was no weed emergence due to development of adequate canopy cover, which suppressed late emerged weeds. These results indicate that post-emergence application of chlorimuron-ethyl was as good as HW in reducing weed count (Behera *et al*. 2005, Jadhav and Gadade 2012).

Seed yield was significantly influenced by the treatments of tillage and crop establishment but the differences in stover yield were not significant (Table 1). Seed yield was the highest under CT–raised-bed, which was on par with CT-flat and ZT-raised bed. The lowest seed yield was under ZT-flat-bed, which was significantly lower than CT-raised-bed. Weed management treatments brought about large increases in crop productivity, when weeds were controlled effectively by chemical and cultural means. Favourable environment was created within the crop canopy, which led to higher growth and yield attributes, and thereby yield performance. Two weed control practices, viz. pendimethalin + HW and pendimethalin + chlorimuron-ethyl resulted in almost similar

Table 1. Weed growth at 60 days after sowing, and yield of soybean as influenced by tillage and crop establishment, and weed management practices

Treatment	Weed count (no./m^2)	Weed dry weight (g/m^2)	Seed yield (t/ha)	Stover yield (t/ha)
Tillage and crop establishment				
CT – raised-bed	6.13 (39.1)	5.93 (44.5)	2.17	5.36
CT – flat-bed	5.49 (31.9)	5.62 (39.6)	2.31	5.28
ZT – raised-bed	6.11 (38.9)	9.23 (104.0)	1.72	3.96
ZT – flat-bed	5.83 (35.9)	7.41 (69.2)	2.20	4.85
LSD (P=0.05)	0.27	0.37	0.20	NS
Weed management				
Control	8.02 (64.0)	12.2 (151.9)	1.84	4.51
Weed free	3.44 (11.5)	2.56 (6.6)	2.47	5.56
Pendimethalin at 0.75 kg/ha	6.09 (37.0)	7.30 (58.8)	2.15	4.83
Chlorimuron-ethyl at 6 g/ha	6.73 (45.0)	9.69 (97.8)	1.97	4.62
Pendimethalin at 0.75 kg/ha + 1HW	5.03 (25.0)	3.12 (9.5)	2.18	5.01
Pendimethalin at 0.75 kg/ha + chlorimuron-ethyl at 6 g/ha	6.04 (36.2)	7.35 (61.5)	2.00	4.40
CD (P=0.05)	0.27	0.26	0.15	0.65

*Square root transformed values "(X+0.05), original values are in parentheses

Table 2. Effect of tillage and crop establishment, and weed management options on N, P and K uptake (kg/ha) of soybean

Treatment	N		P		K	
	Grain	Stover	Grain	Stover	Grain	Stover
Tillage and crop establishment						
CT – raised-bed	100.1	83.5	12.3	10.2	34.2	95.5
CT – flat-bed	108.1	85.5	13.0	10.5	36.3	96.6
ZT – raised-bed	80.1	80.4	12.5	9.6	34.6	70.8
ZT – flat-bed	103.2	62.1	9.8	7.7	27.2	88.6
CD (P=0.05)	11.4	NS	1.20	NS	3.78	NS
Weed management						
Control	85.8	73.5	10.4	9.2	29.0	83.5
Weed free	115.1	90.7	13.9	11.6	38.8	102.5
Pendimethalin at 0.75 kg/ha	100.1	77.0	12.5	9.4	34.1	88.1
Chlorimuron-ethyl at 6 g/ha	92.5	76.0	11.2	8.7	31.1	84.8
Pendimethalin at 0.75 kg/ha + 1HW	101.1	79.7	12.2	9.7	34.1	89.7
Pendimethalin at 0.75 kg/ha + chlorimuron-ethyl at 6 g/ha	93.3	70.2	11.2	8.3	31.5	78.6
LSD (P=0.05)	14.2	NS	1.85	NS	4.46	12.03

weed control; thus gave equal seed and stover yield, which was significantly higher than unweeded control. The mean increase in seed yield under these treatments was 39.1%. The loss of seed yield in unweeded control was 38.3%. Mishra and Singh (2009) also found a similar response with the application of 1.0 kg/ha of pendimethalin + hand weeding at 20-30 DAS.

Concentration of N, P and K in seed and stover of soybean was not influenced due to tillage and weed management (data not given). However, the uptake of nutrients was significantly different under tillage and weed management practices (Table 2). The uptake increased due to higher biomass production under different treatments. The nutrient uptake was the highest under CT-raised-bed, while the lowest value was observed under ZT-flat-bed. These results indicate that better crop growth following reduced weed infestation under CT and raised-bed condition provided adequate supply of nutrients to the crop plants, leading to higher nutrient uptake. Weed management practices caused large and significant differences in nutrient uptake. The uptake of N and K was maximum under pendimethalin + HW, which was significantly more than pendimethalin + chlorimuron ethyl. However, all the five weed control treatments were significantly superior to unweeded control. The decrease in uptake of N, P and K under unweeded control was to extent of 30.2-37.0%. These variations were evident from the fact that the weeds removed large quantity of nutrients under unweeded control, while under other weed management treatments, the nutrients available in soil were effectively utilized by crop plants for growth and development.

CONCLUSION

Seed yield of soybean was the highest under CT–raised-bed, followed by ZT-raised-bed, CT–flat-bed and ZT-flat-bed. Application of pendimethalin + HW and pendimethalin + chlorimuron-ethyl resulted in almost similar weed control efficiency and gave equal seed yield. It was concluded that soybean can be grown under permanent raised-bed with pre- and post-emergence herbicides for realizing higher productivity.

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Tillage, crop establishment and weed management methods in rice-based conservation agricultural system

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Tillage affects the amount of soil microbial biomass and the structure of the soil microbial community. Conservation tillage led to positive changes in the physical, chemical and biological properties of a soil (Bescanca *et al.* 2006). Conservation tillage is known to increase soil organic carbon on the soil surface layer. Crop residue, manure and no-tillage cultivation on agricultural land are regarded as techniques for carbon sequestration through their ability to increase SOC. Hence, field experiments were carried out to assess the effect of tillage, crop establishment and weed management methods on soil microbial and organic carbon contents in rice-based conservation agricultural system.

METHODOLOGY

Field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during *Kharif* and *Rabi* seasons of 2012-14. Transplanting with conventional tillage for *Kharif* and *Rabi* rice (T_1), Transplanting with conventional tillage *Kharif* and zero tillage *Rabi* rice (T_2), Transplanting with zero tillage + crop residue for *Kharif* and *Rabi* rice (T_3), Direct sowing with conventional tillage for *Kharif* and *Rabi* rice (T_4), Direct sowing with conventional tillage *Kharif* and zero tillage *Rabi* rice (T_5) and direct sowing with zero tillage + crop residue for *khzarif* and *Rabi* rice (T_6) were in main plots with rice fallow summer greengram with zero tillage. Recommended herbicides (Transplanted rice - PE butachlor 1.0 kg/ha for *Kharif*, PE pretilachlor 1.0 kg/ ha for *Rabi* and direct seeded rice - PE pretilachlor (S) 0.45 kg/ha) (W_1), Integrated weed management (Transplanted rice - PE butachlor 1.0 kg/ha for *Kharif*, PE pretilachlor 1.0 kg/ha for *Rabi* and direct-seeded rice - PE pretilachlor (S) 0.45 kg/ha + inter crop with *Sesbania* incorporation and mechanical weeding on 35 DAS/T)(W_2) and unweeded check (W_3) were in sup plots. Rice variety ADT (R) 45 for *Kharif* 2012 and 2013 and CO (R) 50 during *Rabi* 2012-13 and 2013-14 were raised. Greengram CO6 was used during 2013 and 2014. The trial was laid out in strip plot design with three replication.

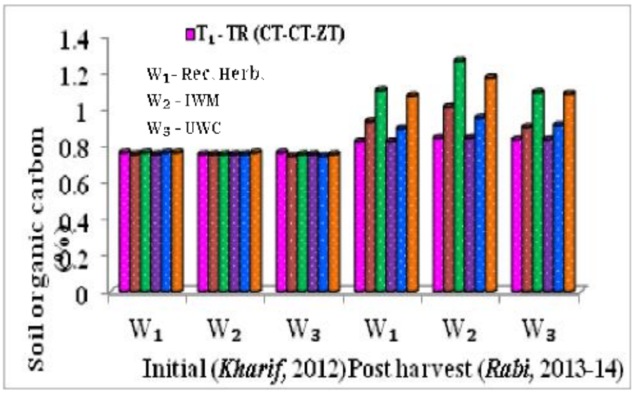

Fig. 1. Tillage, crop establishment and weed management methods on initial and post harvest soil organic carbon(%) in rice based conservation agriculture system

Table 1. Tillage, crop establishment and weed management methods on microbial population (CFU/g of soil) of rice under rice based conservation agricultural system.

Treatment	Bacteria x 10^6 CFU/g of soil				Fungi x 10^5 CFU/g of soil				Actinomycetes x 10^3 CFU/g of soil			
	Kharif 2012	*Rabi* 2012-13	*Kharif* 2013	*Rabi* 2013-14	*Kharif* 2012	*Rabi* 2012-13	*Kharif* 2013	*Rabi* 2013-14	*Kharif* 2012	*Rabi* 2012-13	*Kharif* 2013	*Rabi* 2013-14
Crop establishment and Tillage												
T_1	73.2	74.7	73.3	72.5	48.4	47.3	45.2	45.7	26.4	28.6	28.0	27.0
T_2	76.3	82.2	78.0	79.7	48.4	49.6	47.3	47.4	28.0	31.0	30.2	29.3
T_3	84.6	89.1	92.6	86.4	53.3	55.0	63.4	52.5	32.3	35.2	35.7	33.2
T_4	70.5	71.5	71.2	69.4	46.0	46.3	44.3	44.4	25.9	27.3	27.7	26.3
T_5	74.1	81.0	75.6	78.5	47.6	48.0	47.1	45.6	27.5	30.0	29.1	28.6
T_6	83.6	87.6	88.3	85.0	50.2	52.0	61.4	49.6	30.2	32.6	33.6	30.8
LSD (P=0.05)	4.0	3.8	5.4	3.9	2.8	1.7	1.6	1.9	1.9	1.7	2.1	1.2
Weed management methods												
W_1	67.7	71.8	71.4	69.7	47.5	48.5	47.7	46.1	26.9	29.1	29.7	27.7
W_2	99.0	103.0	103.6	99.9	53.7	55.7	64.0	53.4	33.4	36.5	36.3	34.7
W_3	64.5	68.2	64.5	66.2	44.9	44.8	42.6	43.0	25.0	26.7	26.6	25.3
LSD (P=0.05)	4.0	3.8	5.4	3.9	2.8	1.7	2.9	1.9	1.9	1.7	2.1	1.2

RESULTS

Higher post harvest soil organic carbon (%) was recorded in transplanted rice under zero tillage + crop residue in ZT+CR-ZT+CR-ZT with PE butachlor 1.0 kg/ha for *Kharif* and PE pretilachlor 1.0 kg/ha for *Rabi* + inter crop with *Sesbania* incorporation and mechanical weeding on 35 DAT (Table 1). This might be due to reduced carbon loss in zero tillage system as compared to conventional tillage, incorporation of *Sesbania* and crop residue improved the soil biological activity and decomposition of microbes increased the organic carbon content.

Microbial population, *viz.* bacteria, fungi and actinomycetes increased in transplanted rice with zero tillage + crop residue in ZT+CR-ZT+CR-ZT system PE butachlor 1.0 kg/ha for *Kharif* and PE pretilachlor 1.0 kg/ha for *Rabi* + inter crop with *Sesbania* incorporation and mechanical weeding on 35 DAT(Fig. 1). Immediately after incorporation of organic materials into soil, the plant materials are subjected to the transformation and decomposition process of heterotrophic microflora and *Sesbania* intercrop significantly increased the microbial population many folds. Similar increase in bacterial and fungal population was reported by Biederbeck *et al.* (2005).

CONCLUSION

Transplanted rice under zero tillage + crop residue in ZT+CR-ZT+CR-ZT with PE butachlor 1.0 kg/ha for *Kharif* and PE pretilachlor 1.0 kg/ha for *Rabi* + inter crop with *Sesbania* incorporation and mechanical weeding on 35 DAT recorded significantly higher soil organic carbon (%) and microbial population.

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Effect of time of planting and weed management in direct-seeded aromatic rice at foothills of Jammu and Kashmir

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Rice (*Oryza sativa* L.) is the important staple food crop of India which provides food security to about 77 per cent of the country's population. Out of 42.2 million hectares of rice area in the country basmati or aromatic rice is cultivated over an area of about 7.76 million hectares with production of about 6.5 million tonnes and achieves an export of about 11.96 million tonnes, (Anonymous 2013). Basmati rice being a relatively long duration crop needs early establishment to avoid stress periods which lead to lodging and lower seed setting. Direct dry drilling can be an option for early establishment of rice crop in the months of June or July instead of transplanting in August that will enable the crop to avoid transplanting shock and may lead to sturdy stem. The low productivity of basmati rice-wheat system can be attributed to several limiting factors and all but one important factor amongst those has been the poor weed management which becomes more relevant under direct seeding rice culture where owing to upland conditions weeds achieve an advantageous position. For controlling weeds in basmati rice in Jammu region, a number of pre- and post-emergence herbicides have already found their place in cultivation package of rice however continuous use of some of the herbicides may result in development of herbicidal resistance in weeds over the time. Hence the present investigation was undertaken.

METHODOLOGY

A field experiment was conducted at Agricultural Research Farm, SKUAST-J, during *Kharif* seasons of 2012 in split- plot design replicated thrice. The main plot treatments consisted of two times of planting *viz.*, 15th June and 10th July and sub plots comprised of seven weed management treatments *viz.*, weedy check, weed free, azimsulfuron at 35 g/ha at 20 DAS, cyhalofop- butyl + 2,4-D at 90 g/ha + 0.5 kg/ha at 30 DAS, bispyribac at 30 g/ha at 30 DAS , anilophos + ethoxysulfuron @ 0.375 + 0.015 kg/ha at 15 DAS and pre-emergence oxadiargyl at 100 g/ha. Basmati rice variety" *Basmati 370*" was direct seeded as per main plot treatments. The crop was fertilized with 30 kg N, 20 kg P_2O_5 and 10 kg K_2O /ha through urea, diammonium phosphate and muriate of potash respectively. Data on weed count, weed dry weight, yield and economics were recorded.

RESULTS

The experimental field was mainly infested with *Echinochloa crusgalli, Cynodon dactylon, Commelina benghalensis, Cyperus rotundus, Cyperus difformis* and *Ammania baccifera*. Time of planting and weed management treatments significantly reduced the total weed count and dry matter of weeds at 60 DAS. As regards to crop yield, statistically non-significant results were obtained with respect to time of planting. Post-emergence application of cyhalofop-butyl + 2,4-D at 90g/ha + 0.5 kg/ha at 30 DAS followed by treatments bispyribac at 30 g/ha and anilophos + ethoxysulfuron at 0.375 + 0.015 kg/ha significantly reduced the weed density, weed biomass and resulted in 77.3%, 65.5% and 58.0% higher grain yield compared to weedy check . These results are in conformity with the findings of Choubey *et al.* (2001). The B:C ratio was found maximum with cyhalofop-butyl + 2,4-D at 90 g/ha + 0.5 kg/ha, bispyribac as post-emergence at 30 g/ha and anilophos + ethoxysulfuron post-emergence at 0.375 + 0.015 kg/ha .

Table 1. Effect of time of planting and differential weed management treatments on weed growth, yield and B:C ratio in rice

Treatment	Weed Count at 60 DAS (no./m^2)	Weed dry weight at 60 DAS (g/m^2)	Grain Yield (t/ha)	Weed Control Efficiency	B:C ratio
Time of planting					
15th June	10.92 (118.3)	9.98 (98.8)	19.02	-	1.61
10th July	12.32 (150.8)	11.38 (128.6)	18.03	-	1.48
LSD (P=0.05)	1.23	0.52	NS	-	
Weed Management					
Azimsulfuron at 35 g/ha	9.88 (96.7)	9.29 (85.4)	1.61	58.36	1.78
Cyhalofop-butyl + 2,4-D at 90 g/ha + 0.5 kg/ha	8.23 (66.7)	7.43 (54.3)	2.11	73.52	2.66
Bispyribac at 30 g/ha	8.37 (69.2)	7.71 (58.5)	1.97	71.47	2.56
Anilophos + ethoxysulfuron 0.375 + 0.015 g/ha	8.59 (72.1)	7.86 (60.9)	1.88	70.31	2.33
Oxadiargyl at 100 g/ha	9.90 (97.2)	9.32 (85.9)	1.51	58.12	1.77
Weedy check	17.29 (258.1)	14.35 (205.1)	1.19	0.00	1.34
Weed Free	1 (0.00)	1 (0.00)	2.51	100	2.82
LSD (P=0.05)	0.43	0.39	0.26	-	-

*Figures in parenthesis are original values subject to "x+1 square root transformations

CONCLUSION

Post-emergence application of cyhalofop-butyl + 2,4-D was found effective in controlling mixed weed flora irrespective of date of planting in direct seeded aromatic rice.

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Integration of nitrogen fertilizer and weed management practices affect weed dynamics and competition in dry-seeded rice

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Direct-dry seeded rice has been the predominant rice (*Oryza sativa* L.) cultivation system in upland rain-fed rice ecosystem. However, farmers in many Asian countries, including India, are shifting their rice production system from traditional puddle –transplanted rice to direct seeded either wet or dry seeded rice cultivation system. Such shift is driven by labour and ever increasing water scarcity. The aerobic soil conditions and dry-tillage practices, besides alternate wetting and drying conditions, are not only conducive for germination and growth of highly competitive weeds, but also causes serious N losses which reduces grain yields ranging between 50-91% in DSR . Nitrogen fertilizer has been reported to break dormancy of certain weed species and thus may affect weed infestation (Agenbag and Villiers 1989). Not only can weed reduce the amount of N available to crop, but also growth of many weed species is promoted by higher soil N levels (Morales- Payan *et al.* 1998) Therefore, knowledge of effects timing of N fertilization on weeds and crops grown in competitive mixture may be a promising cultural approach to integrate with herbicide based weed management. A field study was undertaken to determine the response of weeds and rice to various timing of N application and weed management in dry-seeded rice system. Information generated in the study will help in developing integrated and cost-effective weed management strategy in dry-seeded rice system.

METHODOLOGY

A field experiment was conducted during rainy (*Kharif*) season of 2012 and 2013 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. A combination of 24 treatments consisting of 4 nitrogen application time (main plot) and 6 weed management treatments (sub-plot) were evaluated in a split-plot design (Table 1). Rice variety '*HUR-1O5*' was dry-seeded at seed rate of 40 kg/ha in 20 cm spaced rows. A uniform dose of 120 kg N /ha, 60 kg P_2O_5 /ha and 40 kg K_2O /ha were applied in all the plots. Full dose of phosphorus and potash were applied as basal application and nitrogen was applied as per timing of N application under treatments. Data on weeds growth parameters and weed control efficiency were recorded at 60 days after sowing. Rice yield attributes and yields were also recorded during the course of investigation.

RESULTS

Crop was severely infested with grassy weeds, *viz. Echinocloa colona* and *Echinocloa crusgalli*. Sedges consisted of *Cyperus rotundus*, *Cyperus iria* and *Fimbristylis miliaceae* and broad leaved weeds: *Eclipta alba*, *Ammania baccifera*, *Caesulia axillaris* and *Phyllanthus niruri* were also observed.

Table 1. Effect of nitrogen application time and herbicides on weed growth, yield attributes and grain yield of direct seeded rice (pooled over 2 year)

Treatment	Total weed density* (m^2)				Panicles / meter row length				Grain yield (kg/ha)			
	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
Weedy check	19.68 (387.4)	16.83 (282.82)	16.00 (255.7)	18.51 (22.1)	39.33	44.50	47.17	40.00	1255	1564	1775	1415
Weed free	0.71(0.00)	0.71(0.0)	0.71(0.0)	0.71(0.0)	62.83	77.83	87.00	67.00	4933	5154	5231	4870
Pendimethalin at 1 kg/ha	16.17(261.5)	13.69 (187.5)	13.25 (175.3)	15.61 (243.6)	49.00	55.67	58.17	52.17	2656	3684	3211	3099
Pendimethalin 1 kg/ha *fb* metsulfuron methyl + chlorimuron (2+2 g/ha)	12.26 (149.8)	10.52(110.5)	9.74(94.3)	11.64(135.2)	55.00	65.17	66.67	59.17	3475	4452	4329	3893
Pendimethalin 1 kg/ha bispyribac + carfentrazone (25+20 g/ha)	9.80 (95.70)	8.75 (76.17)	8.27 (67.96)	9.33 (86.71)	58.17	75.67	84.33	62.33	4098	4743	5091	4541
Pendimethalin 1 kg/ha *fb* bispyribac + ethoxy -sulfuron (25+18 g/ha)	10.28 (105.2)	9.20 (84.3)	9.06 (81.3)	10.06 (101.2)	57.33	71.17	75.00	61.83	4079	4742	4918	4401
	LSD (P=0.05)				LSD (P=0.05)				LSD (P=0.05)			
W at same N	0.74				6.63				315.01			
N at same W	0.78				7.72				354.97			

*Observations recorded at 60 DAS; Figures in parentheses are the original values; transformed by using square root (x + 0.5); Note: N_1-¼ basal + ¾ at 4 week after sowing (WS), N_2- 1/3 2 WS +1/3 4WS +1/3 6 WS, N_3- ¼ 2 WS + ¼ 4WS + ¼ 6 WS + ¼ 8 WS, N_4- ¼ basal + 1/2 4WS + ¼ 6 WS, *fb*- followed by

Integration of nitrogen application time with herbicides treatment caused significant reduction in total weed density and dry weight at 60 days after sowing and increased number of panicle / meter row length and grain yield of rice (Table1). Pendimethalin 1.0 kg / ha *fb* bispyribac + carfentrazone (25 g + 20 g/ha) under nitrogen application at ¼ 2WS + ¼ 4WS + ¼ 6WS + ¼ 8WS was most effective in reducing the weed density and weed dry weight and found at par with pendimethalin 1.0 kg / ha *fb* bispyribac + ethoxysulfuron (25 g + 18 g) /ha and recorded significantly less weed indices over other herbicidal treatments.

Treatment combination of ¼ 2WS + ¼ 4WS + ¼ 6WS + ¼ 8WS and pendimethalin 1.0 kg / ha *fb* bispyribac + carfentrazone (25 + 20 g/ha) produced significantly more number of panicles per row length and recorded maximum grain yield than all the other treatment combinations, but was comparable to pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron (25 + 18 g/ha). The minimum grain yield was recorded under weedy check at all the time of nitrogen application.

CONCLUSION

The present findings indicated that skipping the nitrogen application at sowing and applying at ¼ 2WS + ¼ 4WS + ¼ 6WS+ ¼ 8WS and sequential application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone (25g+20 g/ha)was the most effective treatment combination to manage weeds and realize higher grain yield in dry-seeded rice.

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Weed management in no-tilled dibbling maize within rice residue

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Among the yield limiting factors weed is considered as a major constraint in maize cultivation. Reduction in maize grain yield due to weeds ranged from 40 to 60% depending upon the intensity and types of weed flora (Sunitha and Kalyani 2012). Increased weed problems and other irreversible damage caused by conventional tillage practices led to the need of exploring alternate crop establishment techniques. It has been the greatest challenge to bring the small land holder under conservation tillage practices as small fragmented lands became in accessible for operating tractor driven 6 or 11 tynes zero tillage machines. Therefore, no-tilled dibbling method was taken into consideration for bringing small land holder under conservation tillage practices.

METHODOLOGY

The experiments were carried out during winter season of 2012-13 and 2013-14 at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India. Eight treatments comprising of varying doses of 2,4-D (post-emergence treatment), atrazine with combined application as pre-emergence and post -emergence treatment, pendimethalin followed by atrazine, unweeded check and complete weed-free treatments were arranged in a randomised block design with four replication. 2,4-D sodium salt and pendimethalin (stomp extra-38.7% EC) was used during first year and 2,4-D ethyl ester & pendimethalin (Dhanutop-30% EC) was used during 2nd year. A small locally made narrow iron spade known as dibbler was used to open the hole/slot within rice anchor residue in which hybrid maize seeds (*900 M Gold*) were dibbled manually at the depth of 6 cm at 60 cm X 30 cm spacing with the seed rate of 19 kg/ha. Glyphosate (1.5 kg/ha) was applied one week before sowing as pre-plant desiccators. Pre-sowing irrigation was given four days before sowing operation. The NPK ratio of 130:60:85 kg/ha was applied. Vermicompost 200 kg/ha, fertilizer mixture (10:26:26) 225 kg/ha, mixture of chloropyriphos (500 ml trade product) + rice husk (2 kg) + molasses (250 g) per 1333 m^2 were applied together with handful mixture at the time of dibbling. Urea was top-dressed in two split doses (112.5 kg/ha each) during 28-30 days after sowing (DAS) and 50-55 DAS. MOP (45 kg/ha) was also top dressed during 50-55 DAS of along with final top dressing of nitrogenous fertilizer. Data on weed growth, yield performance and economics were recorded.

RESULTS

The highest weed control efficiency and lowest weed index values were registered with atrazine (1.0 kg/ha) as pre-emergence + atrazine (1.1 kg/ha) as post-emergence. The major weed flora were *Polygonum persicaria, P pensylvanicum, P orientale, Oldenlandia diffusa, Oldenlandia aquatic,Oxalis corniculata, Stellaria media, Stellaria aquatic, Physalis minima, Solanum nigrum, Hydrocotyl ranunculoides, Ageratum conyzoides* (appeared at latter part of crop growth), the sedge like *Cyperus rotundus* and the grasses like *Cynodon dactylon, Digitaria ciliaris, Setaria glauca, Echinochloa* sp. Among these weeds *Polygonum sp., Cynodon dactylon, Digitaria ciliaris, Setaria glauca* were highly aggressive in maize. Complete weed-free treatment recorded the highest grain yield (9.56 to 10.64 t/ha) at par with atrazine 1.0 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence (9.30 to 10.40 t/ha) and atrazine 0.75 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence (9.08 to 10.12 t/ha). Combination of atrazine pre- and post-emergence recorded the maximum net returns (₹ 93,648.61 /ha to 1,21,052 /ha) and net returns per rupee invested (1.88 to .2.31).

Table 1. Weed control efficiency, yield and economics of maize as influenced by different weed management treatments.

Treatment	Weed control efficiency (%) at 75 DAS		Weed index		Grain yield (t/ha)		Net returns (×10^3 ₹/ha)		Net returns per rupee invested (₹)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
2,4-D 0.50 kg/ha	38.49	42.81	47.21	45.00	5.03	5.83	35.113	51.227	0.73	1.00
2,4-D 0.75 kg/ha	47.43	53.67	45.22	43.41	5.21	5.96	38.568	52.907	0.80	1.02
2,4-D 1.00 kg/ha	48.61	55.96	43.63	42.45	5.33	6.05	43.764	54.093	0.90	1.04
Pendimethalin {0.90 kg/ha (Y1) 0.70 kg/ha (Y2)}+ atrazine 1.1 kg/ha	63.36	74.28	16.23	12.82	7.95	9.18	75.051	101.531	1.49	1.92
Atrazine 0.75 kg/ha + atrazine 1.1 kg/ha	71.13	77.42	4.54	3.39	9.08	10.12	90.960	117.502	1.83	2.25
Atrazine 1.00 kg/ha+ atrazine 1.1 kg/ha	76.68	80.45	2.05	1.25	9.30	10.40	93.649	121.052	1.88	2.31
Unweeded check	00.0	00.0	60.74	62.34	3.76	3.95	19.707	27.100	0.41	0.53
Complete weed-free	100	100	00.0	00.0	9.56	10.64	-	-	-	-
LSD (P=0.05)	-	-	-	-	9.73	13.68	-	-	-	-

CONCLUSION

The concept of no-tilled dibbling technique within the rice anchor residue and fertilizer placement turned out as a successful crop establishment technique for maize for small land holder. Application of glyphosate (1.5 kg/ha) as pre-plant desiccators followed by application of atrazine 1.0 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence treatment has been found effective in managing weeds and also became profitable in maize cultivation under no-tilled dibbling technique.

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Efficient weed management through conservation agricultural practices

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It is imperative to keep the crop fields free of weeds forbetter crop establishment. "Pre-plant" vegetation can include a fall-seeded cover crop or an old grass or alfalfa hay crop; or it can simply be weeds that emerge prior to crop establishment. Manual weeding is increasinglybecoming difficult task due to labour shortage and higher wages. Weed control using herbicides, though effective and economical, may result in the development of herbicide-resistant weeds and adversely affect the environment. Successful implementation of conservation agriculture (CA) systems depends largely on a good understanding of weed seed bank dynamics in soil and management practices. CA is the adoption of innovative crop rotation in which crops are planted in minimum, no-till, or drastically reduced tillage systems with some crop residue retention on the soil surface to reduce unproductive losses of water through evapo-transpiration and hence, control weeds. Thus, CA is a concept for optimizing crop yields, economic, and environmental benefits. CA has developed to a technically viable, sustainable and economic alternative to current crop production practices.It involves integration of minimal soil disturbance, residue retention and sensible/profitable cropping /farming systems.

Weed management through conservation agriculture-based practices

Reduced or zero-tillage creates unsuitable conditions for weed seed germination, so decreases the weed population (Benech-Arnold *et al.* 2000). Weeds have been shown to germinate 50-60% less in CA in rice-wheat systems because the soil is less disturbed and less grassy weeds (*Phalaris minor* Retz.) germinate than in tilled soils (need a reference). CA practices like zero tillage and bed planting has resulted in 50-60% reduction in the population of *P. minor*. Zero tillage can reduce weed problems and make management easier if weeds are managed effectively in the initial 2-3 years. Besides, it may also reduce the emergence of some weed species because seeds at the soil surface are more prone to predation and desiccation. As compared to the conventional tillage option, lower weed population and higher yields are observed when seeds are sown using zero-till in standing crop residues along with the application of herbicides in a proper combination, sequence, and rotation.

Deep and frequent tillage operations experience higher weed population by exposing old and dormant weed seeds by providing suitable climate for germination. CA based practices, that is, permanent no-till residue managed beds and double no-till (zero-till direct-seeded rice- zero-till wheat) reduced weed infestation in rice-based cropping systems of Eastern Uttar Pradesh due to less weed seed bank disturbance in soil and proper cover of soil by the residue (ISWS News Letter 2013). However, conventional tillage helps in breaking dormancy of weed seeds through O_2 diffusion into the soil, CO_2 removal from the soil, increased temperature, and increased nitrate levels. Whereas, minimum tillage or zero-tillage holds the weed seeds on the soil surface that increases the predation possibility of weed seed. Zero- till (ZT) DSR with anchored residue was found to be the most effective in minimizing weed density, dry weight, and nutrient depletion by weeds. ZT rice–ZT wheat recorded higher growth, yield attributes, and yield of wheat due to higher weed control efficiency and better crop establishment over conventional tilled (CT) rice–CT wheat (Kumar 2014) .

Principles of CA dictate at least 30% of the soil surface covers with a residue. Modification of microclimate of soil helps to increase the soil carbon content and weeds suppression. There also has a possibility of lesser interactions between soil and weeds seed favouring in lower weeds emergence. Addition of organic matter increases the microbial activity in soil that potentially increases the weed seed decay. The residues on soil surface help to maintain higher soil moisture by lower evaporations and maintain favourable conditions for microbial populations and accelerate the microbial decay of weed seeds. Relatively warmer climate and a higher temperature increases the rate of weed seed decay. Residue retention with *Trichoderma* application and residue retention alone was found more effective over the residue removal in minimizing the weed density and total dry weight in ZT wheat (Kumar 2009).

Appropriate crop rotations and growing of cover crops during a fallow period helps to suppress the weed population by smothering and allelopathic effects. Growing green manures or cover crops planted in the minor season or as a relay crop efficiently suppresses weed growth. Teasdale *et al.* (2004) reported lower weed seed bank and abundance of the broadleaf weed in rotation of wheat, maize, and soybeans. Permanent residue covers reduce the sunlight exposure of weed seeds and compete with the weeds for space and nutrient. *Sesbania* as a cover crop significantly reduced sedges and broadleaved weeds in ZT directseeded rice. Hobbs (2007) argues that CA reduces the problem of weeds by 50-60% by inhibiting weed germination through mulch or cover crops. Cover crops may affect weed community dynamics through alteration of nutrient cycling processes, particularly N cycling. Use of the cover crops and organic amendments promotes the fungal, bacterial, and mycorrhizal communities that may be detrimental to weeds and beneficial for the crops. Organic ZT retains more weed seeds on the soil surface and provide better habitat for seed predators. However according to Barberi (2002), physical effects of cover crops are the most important to reduce weed population. Cover crops can compete with weed species for necessary resources such as light, water, and nutrients; release allelochemicals into the soil which may be detrimental to nearby competing weed species, particularly for small-seeded weeds. Cereals cover crops, like rye (*Secale cereale* L.) and oat (*Avena* sp.), can provide longer weed control throughout the season and also reduce available soil nitrogen. Rye has long been reputed to produce allelopathic compounds.

CONCLUSION

Adopting CA based practices with minimum soil disturbances, need based residue retention and sensible crop diversification can be an efficient and sustainable weed management option for minimizing weed infestation, enhancing resource-use efficiency, and quality of the environment.

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Weed management and conservation agriculture in rice-wheat cropping system

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Due to growing resource degradation problems worldwide, conservation agriculture (CA) has emerged as an alternative strategy to sustain agricultural productivity. The principles of CA in the rice-wheat cropping system may include reduced or no tillage with residue recycling and green manuring, *etc*. The practice of direct seeding of rice and wheat by zero till along with residue retention have emerged as the two cardinal principles of CA. The rice-wheat rotation is one of the most important cropping systems for food self-security in the world. The productivity of the system is decreasing due to pathogens, multi nutrient deficiencies, and weed flora besides increasing soil health problems. The use of green manuring crops having bio-herbicidal characteristics or weed smothering capability would have the additional benefits of adding biomass to soil. Sesbania, which is known to fix a large amount of atmospheric nitrogen,has been tried as a pre rice legume as a source of N (Ladha *et al*. 2000). The present experiment was underway to see the effect of CA based cropping systems on rice and wheat along with weed management practices on yield of rice and wheat and growth of weeds.

METHODOLOGY

A field experiment was conducted during *Rabi* 2013 and *Kharif* 2014 to develop an appropriate establishment method in the rice-wheat cropping system along with weed management practices under an irrigated ecosystem. The experiment was laid out in a strip plot design comprising five establishment methods in main plots and three weed control methods in sub-plots (Table 1). Wheat variety '*UP 2572'* was sown on 8th November, 2013 while rice variety '*Pant Dhan 12*' was sown on 20 June, 2014 in DSR and ZTR plots, wherever transplanting was carried out on 12 July, 2014. Post-emergence herbicide clodinafop 15% + MSM (1%) was applied on 16 December, 2013 in wheat while in rice, bispyribac-Na was sprayed on July 7th, 2014 as early post-emergence in DSR and ZTR and on August 4th, 2014 in transplanted rice.

RESULTS

Conservation agriculture practices had their significant impact on weed dry matter as well as grain yield of rice and wheat crop. The result revealed that among the different establishment methods highest grain yield of wheat was recorded with DSR (ZT) +R-wheat (ZT) + R-sesbania (ZT) while the yield of rice was higher under the conservation method of rice and wheat owing to less density as well as dry matter accumulation of weeds in these treatments. During *Rabi*, wheat growth in zero tillage performed better than the conventional tillage along with residue retained in both rice and wheat crop and *Sesbania* brown manuring within harvest of wheat and sowing of rice while in rice, conventional tillage system performed better even without residue. IWM practices had its impact on weeds and grain yield of both the crops. Significantly less density and dry matter accumulation of weeds and maximum grain yield of both the crops was obtained in this treatment. Grain yield of both the crops was at par in alone application of herbicide and IWM practices. Highest net return and B:C ratio was recorded in the plots where wheat was sown in the system of TPR (CT)- Wheat (ZT)- Sesbania (ZT) whereas in rice it was recorded in the plots where rice was sown/transplanted in the system of TPR (CT)- Wheat (CT). IWM (herbicide + one HW) practice recorded the highest net return and benefit cost ratio in both the crops.

Table 1. Effect of establishment methods and weed management on yield and economics of rice and wheat in rice-wheat cropping system

Treatment	Wheat			Rice		
	Grain yield (t/ha)	Net return x 10^3 Rs/ha	B:C ratio	Grain yield (t/ha)	Net return x 10^3 Rs/ha	B:C ratio
Establishment System						
TPR(CT)-Wheat (CT)	4.2	53.8	2.8	4.6	30.0	1.9
TPR(CT)-Wheat (ZT)-Sesbania(ZT)	4.1	59.0	3.2	4.5	28.7	1.9
DSR(CT)-Wheat (CT)- Sesbania (ZT)	4.0	51.4	2.7	2.4	51.4	1.2
DSR(ZT)-Wheat (ZT)- Sesbania ZT)	3.8	49.6	2.8	1.7	(-)1.8	0.9
DSR(ZT)+R-Wheat (ZT)+R -Sesbania (ZT)	4.7	39.0	2.5	2.4	7.64	1.3
LSD (P=0.05)	3.5	-	-	0.4	-	-
Weed Management						
Rec.herb. Clodinafop (15 %) + MSM(1%) @ 60+4 g/ha	4.5	60.6	3.1	3.1	11.7	1.4
IWM(Herbicide + one hand Weeding)	4.8	65.2	3.1	4.3	25.6	1.8
Unweeded	3.2	39.3	2.4	1.9	(-)2.6	0.9
LSD (P=0.05)	4.0	-	-	0.1	-	-

TPR- transplanted rice, CT- conventional tillage, ZT- zero tillage, DSR- direct seeded rice, R- residue retention, IWM- integrated weed management, MSM- metsulfuron methyl.

CONCLUSION

Among the different establishment methods in the rice-wheat cropping system, the highest grain yield of wheat was recorded under DSR (ZT)+ R- Wheat (ZT)+ R- Sesbania (ZT) while in rice it was with TPR (CT)-wheat (CT). Among the weed management practices, IWM was found superior over the other treatments.

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Impact of tillage, residue and weed management on growth and yield of maize

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Maize (*Zea mays* L.) is an important cereal crop in world after wheat and rice. It is the most versatile crop with wider adaptability in varied agro-ecologies and has highest genetic yield potential among the food grain crops. Maize is predominately a *Kharif* season crop but in past few years *Rabi* maize has gained a significant place in total maize production in India. *Rabi* maize is grown on an area of 1.2 million ha with the grain production of 5.08 million tonnes, with an average productivity of 4.00 t/ha (Singh *et al.* 2012). The overwhelming effort in increasing agricultural production in India is attributed to several changes facingintensive agriculture like excessive tilling of land, water and fertilizer applications as well as risk in environmental pollution and degradation of soil and water resources. Of late, it has been established that disturbing the soil too much through tillage operations is not actually required to obtain good crop yields (Prasad *et al.* 2006). Hence, a study was conducted to investigate the possible effect of tillage and residue management on soil physical properties, crop growth and yield in rice maize system in avertisol of central India.

METHODOLOGY

A long term field trial was initiated at experimental farm of ICAR-Directorate of Weed Research Jabalpur, Madhya Pradesh, India (23°132 N, 79°582 E, and 390 m above mean sea level) during *Rabi* season of 2013, to study the growth and yield of maize with respect to tillage, residue incorporation and weed management practices on weed dynamics, crop productivity, physico-chemical and biological properties of soil under cotton- wheat cropping system in vertisol of central India.The soil of experimental field was clay loam in texture, neutral (7.2) in reaction, medium in organic carbon (0.79%), available nitrogen (312 kg N /ha) and phosphorus (18 kg P_2O_5 /ha) but high in available potassium (291 kg K_2O /ha).The experiment was laid out in split plot design with bigger plot size (18 x 9 m). The main treatment consists of zero tillage and conventionaltillage. The sub treatments contains without residue and with residue. The sub-sub treatments comprises unweeded control, pendimethalin (500 g) + atrazine (500g) and pendimethalin (1000 g) + 1 handweeding. The crop was grown using standard package of practices.

RESULTS

Dominant weeds in the field were: *Medicago denticulata, Avena ludoviciana, Phalaris minor* and *Chenopodium album*. Tillage practices had similar effect on yield of *Rabi* maize and did not differ significantly for yield attributing characters except 1000 grain weight. Zero till practice increased 1000 grain weight (260 g) significantly as compared to conventional tillage (255 g) (Table 1). Weed density was not influenced by tillage practices but significantly higher weed dry matter (112.3 g) was recorded with zero till treatment. Incorporation of crop residue could not make impact on weed density, weed dry matter, number of cobs/plant and 1000 grain weight but it helped in significant increase in plant height (232 cm), number of grain/cob (406) and maize yield (6.19 t/ha) as compared with non residue treatment (table1). Herbicide and integrated treatments significantly influenced the population and dry matter production of weeds. The lowest weed density (49.5) and weed dry matter was recorded with pendimethalin (1000 g) + 1 handweeding which was statistically similar to pendimethalin (500g) + atrazine (500 g) and both were significantly superior to weedy check. The higher grain yield was recorded with weed management practices as compared to weedy check

Table1. Weeds, yield attributing characters and yield influenced by tillage practices, crop residues and weed management practices

Treatment	Total weed density (no/m^2)	Total weed dry matter (g/m^2)	Plant height (cm)	No of cobs/ plant	No of grains/cob	1000 grain weight (g)	Yield (t/ha)
Tillage							
Conventional Tillage	93.2	74.9	222	2.78	398	255	6.01
Zero Tillage	97.6	112.3	223	2.94	396	260	6.07
LSD (P=0.05)	NS	16.53	NS	NS	NS	0.72	NS
Residues							
With previous crop residue	100	104.1	213	2.67	406	261	6.19
Without previous crop residue	89	83.1	232	3.06	388	253	5.89
LSD (P=0.05)	NS	NS	4.77	NS	16.8	NS	0.17
Weed control							
Weedy check	181	192.6	217	2.50	375	252	5.19
Pendimethalin (500g)+Atrazine (500g)	53.6	43.7	217	3.00	395	259	6.10
Pendimethalin (1000 g) + 1 handweeding	49.5	44.8	233	3.08	420	260	6.84
LSD (P=0.05)	24.2	31.79	6.35	0.35	17.5	NS	0.28

CONCLUSION

Though the yield level of ZT and CT were similar but ZT conserves the resources and reduced the input cost. The residue incorporation is beneficial under both the tillage practices and helps in improving yield potential of the crop. The weed management practices efficiently controlled the weeds and increase the crop yield.

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Initiation of irrigation and weed management practices in dry-seeded irrigated (semi-dry) rice

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Dry-seeded irrigated (semi-dry) rice is a system of rice cultivation with upland conditions in the early stages and low land conditions at later stages of crop growth. This system offers the scope to advance rice seeding for the effective use of early season rainfall. The time of conversion of dry-seeded rice to irrigated low land rice is critical for obtaining higher rice yields. However, in dry-seeded rice, weeds and rice emerge simultaneously, and weeds compete with rice plant for light, nutrients and moisture resulting in reduction of grain yield upto 80% (Rao *et al.* 2007). The management practices like scheduling of irrigation and weed management play a crucial role in enhancing the yield of dry-seeded irrigated rice. Hence, the present investigation was conducted.

METHODOLOGY

An experiment was carried out during *Kharif* season of 2003 and 2004 at College farm, PJTSAU, Rajendranagar, Hyderabad with three irrigation schedules (Initiation of irrigation from 45 days after emergence {DAE}, 60DAE and 75 DAE) as main plots and five weed management practices (Pre-emergence application of butachlor at 1 kg/ha *fb* 2, 4-D Na salt at 1 kg/ha at 30 DAE, pre-emergence application of pretilachlor at 0.75 kg/ha *fb* 2,4-D Na salt at 1.0 kg/ha at 30 DAE, interculture at 20 DAE *fb* hand weeding {HW} at 40 DAE, interculture at 20 DAE fb HW at 40 and 60 DAE and unweeded check) as sub plots in split plot design replicated thrice. Data on weeds, yield of rice and its economics were recorded.

RESULTS

Echinochloa species (47.4%), *Cyperus rotundus* (47%), *Eclipta alba* (1.1%) and *Cynodon dactylon* (4.4%) were the dominant weeds at rice harvest. The lowest weed density (4.37 /m^2), weed biomass (27.2 g/m^2)and higher weed control efficiency (84.4%) was recorded with interculture at 20 DAE *fb* HW at 40 DAE and 60 DAE. The time of initiating irrigation did not influence the weed density, weed biomass and weed control efficiency. Yield reduction of 67.4% was observed due to uncontrolled weeds in weedy check.

Significantly higher straw yield (5.06 t/ha), grain yield (2.79 t/ha) and B:C ratio (1.42) was observed with initiation of irrigation at 45 DAE. Among weed management treatments, interculture at 20 DAE *fb* HW at 40 and 60 DAE recorded significantly higher grain yield (3.66 t/ha) and B:C ratio (1.79).Among the herbicides pre-emergence application of pretilachlor at 0.75 kg/ha *fb* 2,4-D Na salt at 1 kg/ha at 30 DAE and pre-emergence application of butachlor at 1 kg/ha *fb* 2, 4-D Na salt at 1 kg/ha at 30 DAE produced on par grain yield (2.21 and 2.32 t/ha), respectively.

Treatment	Weed Density (no/m^2)	Weed biomass(g/m^2)	WCE (%)	Straw yield (t/ha)	Grain yield (t/ha)	BC ratio
Time of irrigation initiation						
45 Days after emergence(DAE)	6.59 (50)	67.5	69.8	5.06	2.79	1.42
60 DAE	6.81 (52)	73.1	71.0	4.84	2.56	1.32
75DAE	6.55 (50)	83.5	73.0	4.05	2.01	1.06
LSD (P=0.05)	NS	NS		0.21	0.23	
Weed management						
Pre-em application of butachlor at 1.0 kg/ha *fb* 2, 4-D Na salt at 1 kg/ha at 30 DAE	6.10 (37)	68.4	60.4	4.48	2.21	1.15
Pre-emergence application of pretilachlor at 0.75 kg/ha *fb* 2,4-D Na salt at 1.0 kg/ha at 30 DAE	6.01 (36)	62.1	63.6	4.67	2.32	1.19
Interculture at 20 DAE *fb* HW at 40 DAE	5.29 (28)	40.0	76.7	5.58	2.89	1.49
Interculture at 20 DAE *fb* HW at 40 and 60 DAE	4.37 (19)	27.2	84.4	6.04	3.66	1.79
Unweeded check	11.48 (132)	175.8	0.0	2.47	1.19	0.66
LSD(P=0.05)	0.85	17.8		0.29	0.35	
Interaction (IxW)						
LSD (P=0.05)	NS	NS		0.6	NS	

CONCLUSION

Initiationof irrigation at 45 DAE and adopting interculture at 20 DAE *fb* HW at 40 DAE and 60 DAE results in higher economic return and yield of dry-seeded irrigated (semi-dry) rice.

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Impact of conservation tillage on weed dynamics in-rice-rice cropping system

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The practice of double cropping of rice in *Kharif* (June – September) and *Rabi* seasons (October – February) in the Cauvery Delta Zone of Tamil Nadu is on the increase because of the development of short and medium duration high yielding rice varieties. Farmers in the rice (*Kharif*)- rice (Rabi) system of the Cauvery delta zone follow crop establishment methods such as puddled transplanted rice. Puddling alone requires 250-300 mm of water during land preparation. This technique requires large amounts of energy, water and labour, which are becoming increasingly scarce and expensive. Conservation tillage practices generally result in higher amounts of soil organic matter (OM), reduced erosion, increased infiltration, increased water stable aggregates and greater microbial biomass carbon when compared to conventional tillage systems (Reeves 1997). However, weed management is critical to obtain profitable yields in reduced tillage systems, and achieving satisfac-tory weed control requires more intensive management by the farmer. When weeds are controlled, crop yield and net return in no-tillage systems are often equival-ent or greater than corresponding conventional tillage systems (Heatherly *et al.* 1994). Hence alternative tillage options that require smaller amounts of these inputs were evaluated at TRRI. Aduthurai for three consecutive years during *Kharif* 2012, 2013 and 2014 and *Rabi* 2012-13, 2013-14 and 2014-15.

METHODOLOGY

The experiment was conducted in split-plot design with three crop establishment methods, *viz.* Conventional tillage (CT), Zero tillage (ZT) and Minimal tillage (MT) in main plots and two cultivars (*ADT 43* and *CORH 3*) in sub plots. The variety '*ADT 43'* was tried in *Kharif* season, while it was replaced with ADT 45 in *Rabi* season due to seasonal influence. Conventional tillage involves one dry ploughing and two passes of cage wheel puddling combined with pre-emergence application of butachlor at 1.25 kg/ha on 3 DAP. In minimum tillage, one dry ploughing with cultivator was done followed by pre-emergence application of butachlor at 1.25 kg/ha on 3 DAP. In zero tillage, the rice stubbles were sprayed with glyphosate at 10 ml/litre of water + 2% Ammonium sulphate. The stubbles were completely dried within 7 days and paddy transplanting was done in the decomposed stubbles without any preparatory cultivation and this was followed by pre emergence application of butachlor at 1.25 kg/ha on 3 DAP. In both conventional and minimal tillage treatments, two hand weeding was done on 20 and 45 DAP.

RESULTS

In general, sedges were predominant, followed by grasses and broad-leaved weeds during both *Kharif* and *Rabi* seasons. *Cyperus rotundus* among the sedges, *Echinochloa colona* among the grass weeds and *Marsilea quadrifolia* among the broad-leaved weeds were more dominant. Tillage treatments significantly influenced the population and dry matter production of weeds. Among the different tillage treatments, the lowest weed density was observed under conventional tillage (puddling) + pre-emergence application of butachlor at 1.25 kg/ha and two hand weeding on 20 and 40 DAP during both *Kharif* and *Rabi* seasons (Table 1). However no significant difference with regard to weed density was observed between the minimal and zero tillage. The cultivars also did not differ in suppressing the weed growth. The results of the study further indicated that though the grain yield was highest with conventional tillage, the net return and BCR was highest with minimal and zero tillage.

Table1. Weed growth, yield and economics as influenced by different treatments (Pooled mean)

Treatment	Weed density (No./m^2)		Weed DMP (g/m^2)		Weed Index		Panicles/m^2		Panicle wt. (g)		Grain yield (kg/ha)		BCR	
Kharif	CORH 3	ADT 43	COR H3	ADT 43	COR H3	ADT 43	CORH 3	ADT 43	CORH 3	ADT 43	COR H3	ADT 43	CORH 3	ADT 43
CT	8	9	3.2	3.6	0.00	0.00	321	310	3.04	2.57	4.66	4.46	1.98	1.90
ZT	22	24	9.9	11.2	5.36	4.71	311	301	2.92	2.51	4.41	4.25	2.01	1.93
MT	21	20	9.8	9.2	1.72	2.69	314	302	2.94	2.50	4.58	4.34	2.01	1.94
Mean	17	18	7.6	8.0	2.36	2.47	315	305	2.97	2.52	4.55	4.35	2.00	1.92
LSD (P=0.05)														
Tillage	3.27		1.45				NS		NS		NS			
Variety	NS		NS				NS		0.03		NS			
Tillage x Var.	5.93		2.95				NS		NS		NS			
Var. x Tillage	NS		NS				NS		NS		NS			
Rabi	CORH 3	ADT 45	COR H3	ADT 45	COR H3	ADT 45	CORH 3	ADT 45	CORH 3	ADT 45	COR H3	ADT 45	CORH 3	ADT 45
CT	11	11	5.0	5.4	0.00	0.00	285	272	2.76	2.51	4.46	4.19	1.89	1.78
ZT	26	25	12.0	10.8	5.61	5.01	278	268.	2.61	2.48	4.21	3.98	1.94	1.83
MT	21	22	9.8	9.6	3.14	3.48	276	270	2.63	2.49	4.32	4.04	1.93	1.80
Mean	19	19	8.9	8.6	2.91	2.83	280	270	2.67	2.49	4.33	4.07	1.92	1.80
LSD (P=0.05)														
Tillage	3.48		1.45				NS		NS		NS			
Variety	NS		NS				NS		0.02		NS			
Tillage x Var.	NS		2.95				NS		NS		NS			
Var. x Tillage	NS		NS				NS		NS		NS			

CONCLUSION

It was concluded that since no marked yield reduction in minimal and zero tillage was observed, zero tillage and minimal tillage could be alternative tillage options in order to reduce the time lag in land preparation besides conserving natural resources especially irrigation water for increasing the rice productivity in the rice-rice cropping system.

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Weed management in soybean under conservation agriculture

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Conservation agriculture systems is being promoted due to its potential to conserve, improve and make efficient use of resources like soil, water and nutrients besides energy savings and environmental benefits. Farmers can save up to 40% of time, labour and fuel in conservation agriculture besides reducing soil erosion, increasing soil moisture conservation, lowering surface run-off of herbicides and fertilizers, and improving profits as compared to conventional agriculture. Weeds are the major biological constraints towards large scale adoption, and are considered to be one of the most important aspects in crop production under conservation agriculture with reduced tillage and no tillage systems, as it does not allow the traditional means of weed management by ploughing while preparing the field for sowing.

Due to presence of crop residue, pre-emergence herbicides alone may not work effectively in conservation agriculture, as they may intercept a considerable amount of soil-active herbicides. Due to less opportunity of using a pre-emergence herbicide in conservation agriculture, timely application of post-emergence herbicides is critical to avoid any yield loss due to weed competition. It is also being advocated to use herbicide mixtures instead of single herbicide to delay the development of resistance in weeds and improve the weed control spectrum under conservation agriculture (Chauhan *et al*. 2012). The information on these aspects of crop production under conservation agriculture is lacking and hence there is a need to develop a strategy for effective weed management through judicious use of effective herbicides either alone or in combinations to increase the sustainability of soybean production which in turn will also ensure that herbicide use remains profitable and environmentally sound over a long period of time under conservation agriculture.

METHODOLOGY

Field experiments were conducted with soybean under conservation agriculture (no till) systems in Vertisols of Central India during *Kharif* 2014 at the Research Farm of ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh. The soil of the experimental field was clayey in texture with low in available nitrogen (266 kg/ha), high in available phosphorus (27.34 kg/ha) and potassium (524 kg/ha). The experiment was laid out in randomized block design with nine treatments replicated thrice. The nine treatments evaluated were (i) Unweeded control, (ii) Two hand weedings at 20 & 40 DAS, (iii) Pre-emergence application of pendimethalin at 1000 g/ha, (iv) Post-emergence application of propaquizafop 100 g + chlorimuron ethyl 9 g/ha at 20 DAS, (v) Post-emergenceapplication of imazethapyr 100 g/ha at 20 DAS, (vi) Pre-emergence application ofpendimethalin at 1000 g/ha *fb* post-emergence application of imazethapyr at 70 g/ha at 30DAS, (vii) Post- emergence application of propaquizafop 100 g + chlorimuron ethyl 9 g/ha at 20 DAS *fb* removal of escaped weeds at 40 DAS, (viii) Post- emergence application of imazethapyr 70 g/ha at 20 DAS *fb* removal of escaped weeds at 40 DAS, and (ix) Pre-emergence application of pendimethalin 1000 g/ha *fb* removal of escaped weeds at 30 DAS. Soybean variety '*JS-335*' was sown in the experimental field at a row spacing of 30 cm during the last week of June, 2014 with the help of zero seed cum fertilizer drill. Recommended rate of fertilizer (30 kg N + 60 kg P_2O_5 + 40 kg K_2O /ha) has been applied uniformly. All other agronomic and plant protection measures were adopted as per the recommended package of practices. Observations on plant growth, yield attributes, weed population and biomass were recorded.

RESULTS

The major weed flora in soybean comprised of grasses (*Echinochloa crusgalli, Panicum javanicum* and *Brachiaria recemosa*), and broad leaf weeds (*Digera arvensis, Alternanthera sessilis, Celosia argentea, Cesulia axilaris, Cyanotis ciliaris and Euphorbia geniculata*). .

Among different treatments significant response of herbicides in terms of suppression in weed population and weed biomass has been recorded as compared to unweeded control. Maximum weed population 453/m^2 was recorded under unweeded control, while the lowest weed population 58/m^2 was recorded with pre emergence application of pendimethalin at 1000 g/ha fbimazethapyr at 70 g/ha at 30DAS which was at par with pre emergence application of pendimethalin 1000 g/ha fbremoval of escaped weeds at 30

Table1. Effect of different treatments on weeds parameters

Treatment	Weed population (/m^2)	Weed biomass (t /ha)	WCE %(biomass)	Seed yield
Absolute control	435.33	3.00	0.00	0.42
Two hand weeding at 20 & 40 DAS (Conventional weed management)	110.67	0.44	85.30	1.61
Pre-emergence Pendimethalin at1000 g /ha	154.33	1.12	62.45	1.16
PoE Propaquizafop 100 g + Chlorimuron ethyl 9 g/ha at 20 DAS	303.00	1.44	51.95	1.08
PoE Imazethapyr 100 g/ha at 20 DAS	259.67	1.26	58.00	1.58
Pre-emergence Pendimethalin at 1000 g/ha *fb* PoE Imazethapyr at70 g/ha at 30DAS	58.33	0.16	94.50	1.78
PoE Propaquizafop 100 g + Chlorimuron ethyl 9 g/ha *fb* removal of escaped weeds at 40 DAS	102.00	1.03	65.53	1.70
PoE Imazethapyr 70 g/ha Fbremoval of escaped weeds at 40 DAS	105.67	1.00	66.58	1.58
Pre-emergence Pendimethalin 1000 g /ha Fbremoval of escaped weeds at 30 DAS	72.00	0.47	84.43	1.64
LSD (P=0.05)	46.02	0.49		0.25

PoE= Post emergence, fb=Followed by

DAS ($72/m^2$) (Table 1). Similarly the lowest weed biomass (0.16 t/ha) and maximum weed control efficiency (94.5%) has been recorded with application of pendimethalin (at 1000 g/ha) *fb* imazethapyr at 70 g/ha at 30 DAS treatment.

Significant response of various herbicidal treatments was recorded as compared to unweeded control. Pre-emergence application of pendimethalin at 1000 g/ha *fb* imazethapyr at 70 g/ha at 30 DAS, post emergence application of Propaquizafop 100 g + Chlorimuron ethy l 9 g /ha at 20 DAS *fb* removal of escaped weeds at 40 DAS, pre-emergence pendimethal in at 1000 g/ha *fb* removal of weeds at 40 DAS gave seed yield comparable to two hand weeding (20 and 40 DAS). While unweeded control recorded significantly lower seed yield and the yield reduction was to the extent of 74% due to weed competition (Table 1).

CONCLUSION

Weeds of soybean based conservation agriculture can be managed with the pre-emergence pendimethalin at 1000 g/ha followed by application of imazethapyr at 70g/ha at 30days after sowing which was comparable to hand weeding (no data).

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