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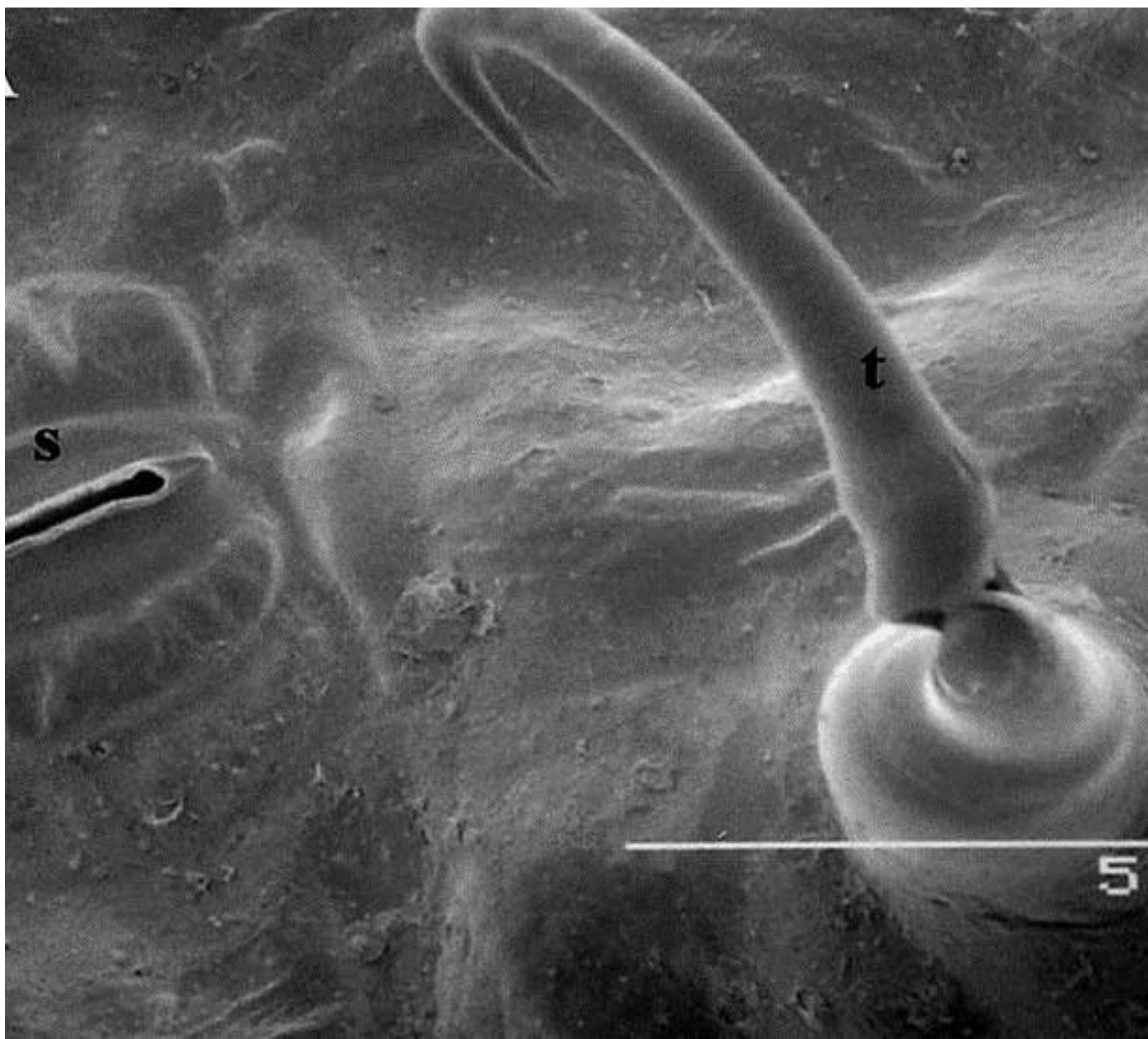

EDITORIAL

Making a Difference- The New '*Weeds*' Journal

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In this Editorial for the first issue of the new journal - *Weeds* - I reflect upon why the Asian-Pacific Weed Science Society (APWSS) decided to launch a journal and why we decided to make it **Open Access** (OA). A journal publication is usually the principal means of recording achievement in science. It is also the most efficient way for scientists to share information. All publications are important to professional societies as a means of sharing knowledge. Over the past five decades, APWSS achieved this objective, primarily through the proceedings of our biennial conferences.

Much has happened in Weed Science over the past five decades. Early APWSS conferences were well-known for introducing new herbicide chemistries, new formulations for different crops and discussions on topics, such as different methods of herbicide application, biological weed control, aquatic weed control and environmental impacts of herbicides. Those early conferences also emphasized the importance of education, extension services, international linkages, and collaborations. In recent times, APWSS Conferences have tackled emerging topics, such as herbicide resistance in weeds, effects of climate change on weeds, potential utilization of weeds as biological resources, sustainable farming, and weed risk assessments. Throughout the Society's history, there has also been an emphasis on educating the affiliated members to influence policies in their own countries, and more broadly, across the region (Chandrasena and Rao, 2017).

Over five decades, APWSS Conference Proceedings have had varying degrees of refereeing, which usually reflect the editorial skills of the host country's committees. Despite some qualitative variations, overall, the proceedings have supported the APWSS ethos of '*learning from each other'.* They have also fostered alliances across member countries to manage weeds better, as envisioned by our founders (see Furtick, 1969).

Publishing a journal, in addition to the biennial conference proceedings, is a significant step forward for the APWSS, as it will boost the public face of the Society. A journal paper typically undergoes a more rigorous peer-review process, than that required for conference communications. This enhanced scrutiny should make a journal paper more authoritative and a better source for citation. Additionally, the publication of a journal should boost the reputation and the regional standing of the APWSS.

In a reputation-based profession, such as scientific research, the importance of publications cannot be overstated. Research that is never published is of little or no value to society. Publishing is almost obligatory to achieve progress in modern science. The publication of a journal paper enables authors to gain acknowledgment from their peers as specialists in their specific research area. Publications in a peer-reviewed journal also give international recognition not just for an individual, but also to an institution. In some cases, where a topic of primary global importance is critically analysed, and reviewed in a publication, the authors' country, or even the region, may also get credit and greater recognition.

Not just another paper!

The 1950's and 1960's saw the emergence of a '*publish or perish*' culture (i.e., publish your research or lose your career). For academics and scholars, this phrase was a constant and often threatening reminder of the importance of publication (Roberts, 1991; Moosa, 2018). During this period, across the world, the number of academic and scientific institutions increased dramatically, stimulating an expansion of research agenda. Scholars with a high frequency of peer reviewed publication attracted attention to themselves and their institutions, which usually ensured the individual's career progress and also more funding for the institution.

The heightened emphasis on publishing and consequent fierce competition for research funding has had deleterious effects, such as poor collaboration between individual researchers and research entities. It also decreased the value of scholarship as scholars spent more time scrambling to publish, rather than dedicate time to developing important research themes that deliver good science for the public. Despite these negative aspects, the quality of journal papers in the latter part of the 20^{th} Century was demonstrably high, not just in Weed Science but in all disciplines. This enhanced quality resulted directly from tighter editorial oversight, combined with tougher peer-review processes by journals. However, the new millennium has seen a proliferation of sub-standard journals, which allow publishers to profit from science communications.

Weeds will avoid adding to the wasteful dump of low-quality papers on weed-related topics, by maintaining publication excellence through the quality control processes, typically associated with legitimate journals. Using experts and experienced reviewers, *Weeds* will be transparent and rigorous in the peer-review process. Instead of publishing for its own sake, *Weeds* will demand contributions that will be valued by scholars interested in Weed Science. The journal hopes to receive, evaluate, and publish not just any paper, but meaningful contributions that will advance the global dialogue on weeds. If managed well, this approach will make the APWSS more influential in the region and within Weed Science.

Mentoring authors to write well

The publication ethos of *Weeds* also extends to helping scientists to write highly readable papers, which are unambiguous, concise and scientifically accurate. In this way, papers published in *Weeds* will be valued by other scientists and are more likely to be cited by them, advancing the broader discipline of Weed Science. It will also enable the journal to attract worthy contributions from the broader community of weed scientists.

Weeds may also be an avenue to improve scientific communications on weeds in our region. Whether we like it or not, English is the primary mode of communication for international commerce and science, primarily because the technologies we rely on today are mostly English-based (e.g., more than 50% of internet websites). Moreover, a quarter of the world's population speaks English. Therefore, there is an onus on scientists in the Asian-Pacific region to obtain a high level of competency in English so that they may benefit from greater recognition of their work. Despite this obvious truth, natives of non-English speaking countries in our region often do not write well in English. "*English is not our native language*" is an excuse that is frequently heard in this discourse.

Although poor English writing may not result in outright rejection of a manuscript, it may well negatively influence the overall impression of the work on the part of peer reviewers and editors alike (Kelly et al., 2014). With scientific writing, as with most other forms of communication, the most direct statement of the intended message is always best. In other words, an author should say what he or she means, without using convoluted arguments.

Weeds requires the Editors to primarily assess the *scientific value* and scholarship of each manuscript submitted. Beyond this, the Editors undertake to help authors improve the structure and grammar of their manuscripts, committing to a mentoring role. Authors can also improve the quality of their papers by addressing referee questions conscientiously. Peer-reviewers use an independent and critical eye to question the scientific validity of the authors' arguments and to assess the value of the contribution from a readers perspective. Ideally, our editors will dissuade authors from succumbing to the relentless pressure to publish at all costs to increase the number of publications, and instead to publish high quality, readable papers.

Time-tested scientific approaches

Cohen (1985) reasoned that '*science is the only cumulative and progressive*' activity of humankind. Typically, scientific advances are incremental and cumulative, in which one small step follows another, building upon existing knowledge. Science is also an intellectual and creative exercise, which begins with open-minded observations and questions, seeking to end with evidence-based answers.

A simple compilation of information will not advance Science, which requires logical, methodical, and critical analysis of data, observations, and assumptions. In advancing knowledge about weeds and how to effectively manage them, our journal will expect all contributors to follow established scientific traditions. *Weeds* will recognize 'good science,' and by extension, good scientific papers, which are based on the strength of evidence obtained through repeated experiments and observations.

The scientific research process, typically, is an iterative, cyclical procedure through which information is continually reviewed and revised. In one way or another, the process involves the following elements:

- The collection and analysis of new or previously existing data for evidence-based conclusions.
- Developing a concept, or theory, as a hypothesis, followed by testing to support it.
- The generation of new ideas and theories through experiments, analysis or new observations, leading to the emergence of a new agenda.
- Applying new technologies, for better precision in measurements, and new methods of data analyses for stronger discrimination of results.
- Refinement of results through replication and extension of the original work, verified by independent review.
- Timely communication of ideas to others and dissemination of knowledge through publication.

Scepticism, openness, sharing, and disclosure are typically associated with the scientific inquiry process. These not only provide the means of identifying theoretical or experimental errors that occur inevitably in science but also imply an obligation to maintain the integrity of the research process. Errors are often corrected by subsequent research or re-examining the data with new analysis, which may lead to better explanations of the results. Scepticism of other scientists, including the referees and editors, is an essential part of the thoughtful examination that all contributions must undergo.

Editors of any scientific journal are 'gate-keepers', responsible for safeguarding established scientific traditions in communications. The Editors of *Weeds* will be committed to maintaining these traditions. They will also uphold ethical principles that every scientist should adhere to, including intellectual honesty, which must be demonstrable at all stages of any scientific work - from developing a hypothesis, through to the investigative research methodology, data analysis, and interpretation. Honesty is a keystone in writing effective communications, worthy of being published.

The *Value* of a Paper

The paramount issue for *Weeds* is the '*value*' of any contribution to the discipline of Weed Science or its various sub-disciplines. Some scholars argue that the *value of* a paper depends upon the reader's interest, perspectives, and background, which have subjective elements (Pandit and Yentis, 2005). However, there are essential elements of a paper, which should merit its publication. These include its originality, critical appraisal, and strength of evidence; e.g., the logic of argument; the soundness of the methods used and the rigour of the statistical testing, where appropriate. If these elements are present in a paper, it should then lead to drawing well-informed credible conclusions, informed by the current knowledge.

Ideally, a paper deserving of publication should also influence '*the way we think*' about a particular topic. Really good, or outstanding papers, would present findings and arguments that may eventually become genuinely valued by others who are interested in the same subject matter. Sometimes, such papers may also kindle new interest in scholars on topics that may not have been of great interest to them, up to that time.

When evaluating a paper, a referee will ask: '*Are there any other possible explanations for these results?*' '*Which specific questions concerning this topic will increase the current knowledge we have? How useful are the results? What are the implications of the findings*? The challenge is for researchers to ask the *right questions,* so they get the right answers.

These days, one comes across plenty of papers, which sacrifice quality for quantity. In some of the lowest quality papers, published mostly in dubious journals, there is often a gap between the conclusions and the primary aims of the inquiry. There are also countless examples of papers, which use a catchy title to attract readers. However, closer scrutiny reveals that the title has little to do with the content of the paper. Often, such papers contain only benign and superficial conclusions with no meaningful discussion.

Weeds will foster a culture of truth-seeking, promoting systematic scientific inquiries and persuasive communications. Each submission to *Weeds* will undergo a rigorous peer-review examination by two or more independent and expert reviewers. The review will be more than simple circling of typographical mistakes. Reviewers may challenge the authors' assumptions and conclusions.

When an article is published, authors could feel confident that reviewers who are knowledgeable about a particular topic have applied a collective judgment as to whether a paper contributes something worthy of publication. Taking a stand to move away from a quantity-driven publishing model to a quality-driven one, *Weeds* will discourage the production of papers just for the sake of a paper.

As a responsible journal, *Weeds* recognizes the value of review papers, which appraise a body of knowledge and articulate the current status of the topic. Good reviews are widely cited, as accomplished scholarship. However, while some articles bill themselves as critical reviews, this is rarely the reality. The over-abundance of reviews we encounter nowadays is a direct outcome of the impact factor metric (Peter Suber, *personal communication*, Aug 2019). Review articles are more highly cited than ordinary research articles, and therefore, boost the impact factors of journals. To be accepted by *Weeds*, a review must do more than just present chronological accounts of any inquiries, findings, data, and information. *Weeds* will encourage contributors to review papers to meaningfully analyze the topic and provide evidence to validate any new findings.

There is also a recent negative trend to produce a review of a convenient topic, although the authors themselves have no demonstrable track record on the subject reviewed. This phenomenon is not a problem if the review is a defendable analysis of data and information from which valid conclusions may arise. However, authors who lack experience in a specific topic can fail to appraise the subject critically, and unquestioningly accept the literature covered. Instead of examining the empirical research, many reviews just group research studies in various shapes and forms and re-cast their main findings, with non-committal conclusions. Such reviews do little to advance scientific knowledge about managing weeds. *Weeds* will insist on a fundamental requirement of scholarly integrity - that if a piece of work is a critical examination or analysis, it has to live up to that billing.

Weeds will also attempt to dissuade authors from two other potentially detrimental practices, which are intertwined with the '*publish or perish*' culture. Prevalent in journals nowadays, the first is 'salami-slicing,' whereby authors split the same research into the smallest possible publishable units, in a bid to enhance productivity (Beaufils. and Karlsson, 2013). Many such papers do not explain why splitting was necessary. In some countries, academics are rewarded for such doubtful productivity, possibly, receiving extra payments for each of the papers they publish. Some researchers may argue that their research findings and data are too much for a single article and that splitting the work into several papers works better. Sometimes, splitting to produce sequential papers, possibly indicated as a series, maybe acceptable to *Weeds* but only with justification.

The second dubious practice is duplicate publication in which researchers publish the same material in different journals with different keywords, captions and co-author variations (i.e., merely changing the order of authors' names) on each occasion. *Weeds* will consider these unethical practices a blight on scientific publishing integrity.

Science behind a paywall?

Most people know that the Internet was created to help scientists share their research efficiently. The question then is – *why are journal fees increasing when the Internet has made sharing information cheaper and more accessible than ever before? Weeds* believes that it is a responsibility of any journal to help scientists take full advantage of the Internet's original purpose and power, to communicate information efficiently and seek ways to collaborate and advance the cause of science.

Over the past two decades, 'paywalls' imposed by publishing companies have become a controversial issue for scientists, who want to publish their research in respected journals. The paywall model is a subscription model, which charges a fee for access to a published paper. Historically, since the 17th Century, modern science thrived because scientists of the day were proud to publish their research and share the joy of their discoveries with the world (Kumar, 2009; Kelly et al, 2014). In those days, knowledge-sharing was achieved through personal journals and books, published with the patronage of wealthy individuals, or through the sponsorship of academic institutions, governments, or professional societies (see Wikipedia, undated).

Until recent times, journals charged authors a nominal fee to cover hard-copy printing, only after accepting a paper for publication. This fee is referred to as the Article Processing Charge (APC). Until the late-1980s, it was quite common for scientists in developing countries to receive an exemption from journal page charges by simply writing to the editor. Nowadays, the world's most prestigious journals have been taken over by global publishing companies, who have to cover all costs and still derive a profit for their investors. This takeover has resulted in the commodification of scientific communications. Investors have discovered that publishing scientific knowledge is a new opportunity to make money. Profit is the singular motivation for the paywalls. Lost in the publishing industry's drive for profit is the brilliance of an inventor or the efforts of a dedicated researcher.

Subscription fees *limit* access to scientific knowledge (Khabsa et al., 2014; Moosa, 2018). For a scientist in a developing country, the consequences of facing a paywall can be utterly dis-empowering. If a scientist is unable to access the full text of an article of interest, then he or she may lack information important for anchoring their study, make improved decisions about experimental designs, or correctly interpret results. Mainly, they will be poorer for the lack of access to information, simply because they cannot afford to pay for it.

Despite the negative side of the paywalls, some journals defend fees stating that the primary aim of fees is to put a *value* on the exclusive content they produce. These journals claim they maintain the quality of published research and make it more understandable and convenient for readers using paid editors, even though they do not pay authors or reviewers. The claim is that science operates more efficiently when new research can be accessed *freely and immediately* by scientists around the world, and 'data-mined' by powerful web-crawling technology that may identify inter-connections that individuals would be unlikely to make otherwise.

Most paywalled journals employ skilled editors, who are not necessarily scientists. They are paid to ensure accuracy, consistency, and clarity in scientific communications. These paid professionals pre-vet papers before peer-review, with the justification that they support the review panels. They also select engaging content to present exciting discoveries, provide catchy titles, and get into marketing through related blog posts. Some publishing staff, working for modest stipends, also undertake the complex typesetting, printing and distribution activities, including Web publishing and hosting. These costs justify hefty access fees.

While this debate will most likely rage longer, various digital technologies and the fast Internet, have all made *open access* to research papers and journals relatively easy. For those who are interested, it is instructive to read Peter Suber's treatise on **Open Access** (Suber, 2012), which discusses both sides of the argument, including strengths and weaknesses. Examining the issue in great detail, Suber stated:

"…Shifting from ink on paper to digital text suddenly allows us to make perfect copies of our work. Shifting from isolated computers to a globe-spanning network of connected computers suddenly allows us to share perfect copies of our work with a worldwide audience at essentially no cost. About thirty years ago this kind of free global sharing became something new under the sun. Before that, it would have sounded like a quixotic dream. Digital technologies have created more than one revolution. Let's call this one the access revolution..."

"…The deeper problem is that we donate time, labor, and public money to create new knowledge and then hand control over the results to businesses that believe, correctly or incorrectly, that their revenue and survival depend on limiting access to that knowledge..." Peter Suber (2012)

Our Journal

In these changing times for academic publishing, APWSS ambitiously took a stand to create a journal that does not charge hefty publication fees, as an initiative to support scientific communications on weeds. The intention of *Weeds* is for an Editorial Board of reputed and experienced scientists to volunteer their time freely, to produce a journal that makes a difference to other scientists' lives. Significant recent advances in computing technology, software and Internet tools enable the cost-effective production of an on-line journal to benefit our community.

APWSS is aware that for some organizations, journals are an essential source of revenue, which fund other activities, such as travel grants for researchers from developing countries. However, making revenue from the journal is not a priority for our Society. Instead, *Weeds* will be launched as a high-quality '**Open Access**' (OA) publishing platform, charging only a nominal administrative fee from the authors to cover the costs of using a journal-management web platform. Once published, all the articles on *Weeds* will be available free to everyone, on-line, for perpetuity.

The search for truth is the vocation of every scientist, a vocation that should inspire each of us to pursue exciting and even controversial ideas, to engage in spirited exchanges with our colleagues and critics, and to counter customary habits of thinking and analysis with new insights and observations (Institute of Medicine, 1992). *Weeds* will attempt to seek the truth about weeds and share that knowledge. The journal guidelines state that *Weeds* is dedicated to *understanding weeds and promoting improved weed management within the context of ecologically responsible and sustainable agriculture and management of our environment.*

To do this, first, we should dispel the harmful myths and bias against weeds, which has long been the enemy of weed research. The bias starts with from the flawed premise that '*all weeds are bad news*' and they need to be controlled at any cost. Inflammatory comments that weeds and other invasive species should be treated as '*guilty until proven innocent*' - reverberate through our discipline. This bias needs to be incrementally reversed. *Weeds* will attempt to foster this change in attitude. We should question such unscientific notions within a discipline that aims to be both multi- and inter-disciplinary, and one that sets a goal to be an active contributor to sustainable ecosystems, sustainable agricultural production, and healthy human societies, which value biodiversity.

Weeds are merely pioneering plants with an innate capacity to colonize disturbed areas rapidly. Weeds have long been regarded as a significant biotic constraint in agricultural production globally. Weeds get blamed quite often for poverty, malnutrition, and food insecurity, which are rampant in developing countries. Other negative impacts of weed abundance are also increasingly recognized by managers and users of forests, parks, nature reserves, waterways, and other areas of human habitation. Nevertheless, *not all weeds are bad all the time, and indeed, not under all circumstances*. Usually, the perception of the viewer determines whether a plant is a weed or not. One person's weed can be another's joy!

There is also compelling evidence that weeds can be biological resources, not just as sources of food, medicines and raw materials for industry, but also in a broad range of environmental rehabilitation applications; e.g. reducing heavy metal contamination from mining sites and industrial effluents, which may pollute waterways and other landscapes. It may be possible to manage and manipulate 'beneficial weed' populations to promote biodiversity across vast landscapes and also to tolerate some level of weed occurrence in agriculture, instead of an *all-out war with weeds* (Chandrasena, 2014).

Traditional uses of weeds by societies needs greater recognition and study. *Weeds* will strive to promote such ideas, as the basis for a balanced understanding of weeds, particularly, their ecological roles in Nature, based on research, scholarship, and disciplined conversations. Embarking on such a conversational journey may reduce the tension between humans and weeds, which is often the result of misinformation. By focusing too much on negative aspects of weeds, and then on tools and technologies for weed control, including herbicides, perhaps, some weed scientists have forgotten that we are dealing with an extraordinary group of plants.

After a slow start in the 1950s, Weed Science has matured by integrating the knowledge of weeds from diverse fields, including biology, ecology, physiology, biochemistry, genetics, and taxonomy (Chandrasena and Rao, 2017). Over more than 70 years, our science has been hugely successful in developing the tools, techniques, and tactics to manage weeds, and help society. The discipline's immense contributions to improved crop production, reduction of other agricultural pests, including insects and plant pathogens, reduced risks to human and animal health, are well-recognized. The maturity of Weed Science is attested by its various applications, which extend well beyond agriculture to broader environmental management.

More importantly, the discipline now recognizes the culpability of the human agency as the most influential factor in the continued evolution of weeds, and the spread of weed species across the globe. The discipline cannot remain static; it must respond to new challenges, not necessarily only from weeds. Among the most significant challenges are climate change and its effects on natural and man-made ecosystems and distribution of weeds across the globe, and the development of herbicide resistance in weeds across the globe, because of overuse of herbicides. The recent interest in glyphosate, the world's most overused herbicide, as a cancer-causing agent (Andreotti, et al., 2018), is also a significant issue that weed scientists and other researchers should be focussing heavily on.

Today, thankfully, simple weed control has been replaced by a more holistic approach, under the theme of Integrated Weed Management (IWM). This strategic approach, developed over the past 30 years, ensures that our discipline contributes to more effective and practical solutions to managing weeds, where they present real problems. As there are no silver bullets to solve weed problems, a primary goal of IWM is to reduce herbicide use and to integrate all available tactics and techniques to manage weeds with an understanding of the causes why they are there in the first place. This approach also requires due consideration of the agencies that cause disturbances, which result in the spread and establishment of weeds. Nevertheless, while dealing with weeds, communicating messages on them in a balanced way, has always been problematic in our discipline. It is always relatively easy for people to malign other organisms for our inability to manage biodiversity and our environments responsibly.

Engaging with weeds is a highly beneficial activity because Weed Science, as a discipline, goes well beyond its scope into other areas of human interest and engagement, such as culture, collaborations, co-existence and human interactions with each other, as well as with Nature. *Weeds* will promote such an engagement and understanding - that all colonizing species are very much a part of the biological diversity of the planet.

Humans will be impoverished if we continue deluding ourselves that we need, to be '*at war*' with weeds in all situations, all the time. When and where weeds interfere in our affairs, their control is justified, but the journal will encourage the view that such activities need to be carried out with an enlightened understanding of the inherent values of weeds, their worth to ecosystems, and ultimately, to humanity.

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SPECIAL EDITORIAL

Founders of the Asian-Pacific Weed Science Society – An Appreciation

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Abstract

The APWSS, born on 22 June 1967, is now 52 years old. It is now taking a major step forward by publishing a dedicated, weed science journal - *Weeds*. In this Special Editorial for the journal's inaugural issue, I am privileged to have the opportunity to reflect on the landmark events, which preceded the Society's birth. We were not born by accident; momentous events within the discipline of Weed Science, and related fields, shaped our birth. It is appropriate, in this first issue of the new journal to acknowledge our Society's gratitude to the three founding fathers. While providing my own views on some important challenges ahead, I recall the essence of what our founding fathers achieved, so the readers might be inspired. We stand tall today because of their vision and commitment, over five decades ago. In 2017, celebrating 50 years of existence as a professional society, we recorded the society's achievements and contributions to Weed Science and the broad spirit in which they were achieved. Applying Weed Science across the Asian-Pacific and possibly, other tropical regions, must continue to be our goal, while continuing to take up new challenges. This will require APWSS to engage more broadly with similar global movements, by networking to share knowledge and experiences to inspire the current and next generation of weed scientists. Given there is little consistency in the way we deal with weeds in the different member countries, developing a common agenda to educate and influence national policies must be a priority for the APWSS in the 21st Century.

Keywords: Asian-Pacific Weed Science Society, Donald L. Plucknett, William R. Furtick, Roman R. Romanowski Jr.

'It All began in a Kitchen'

In a letter to the Asian-Pacific Weed Science Society, on its 40th Anniversary in 2006, one of our founding fathers - Dr. Donald Plucknett, explained that: "...*It all began in a kitchen at the East Kauai Methodist Church*…" His fascinating account leaves little to imagination. It describes our birth as follows:

> *"…The history of the Asian-Pacific Weed Science Society began with the first "Asian-Pacific Weed Control Interchange". The story of its beginnings is an interesting story, involving a number of persons who came together to make it all possible. In 1966, the University of Hawaii and Oregon State University began a new collaborative program to screen new herbicides under sub-tropical conditions in Hawaii. These experiments were linked with similar experiments in Oregon and Chile (an ecological analogue of Oregon). Professor Bill Furtick of Oregon State had pioneered these experiments that demonstrated the efficacy of linked international experiments and international collaboration in weed science. Sometime in 1965 or 1966 Dr. Furtick had met Dr. Roman R. Romanowski, Jr., Assistant Professor of Horticulture at the University of Hawaii, and they began to plan how they could collaborate in weed research. On his return to Hawaii, Dr. Romanowski contacted me regarding possible holding of the annual herbicide trials at the KBS.*

I quickly agreed, and Roman and I brought the matter to the administrators of the UH College of Tropical Agriculture who readily approved. Thus, began a very fruitful and fulfilling collaborative arrangement between OSU and the UH Departments of Horticulture and Agronomy and Soil Science. Every year, when the trials were being conducted, Bill Furtick, Roman Romanowski and I spent a lot of time together, working and talking about how weed science might be expanded even further and strengthened to meet the challenges..."

"…In January, 1967, we (Bill, Roman and I) were relaxing a bit on Kauai after completing work on the annual OSU-UH Herbicide Screening Trials at KBS. We decided to go apart from the crowd for a while and just brainstorm what could and should be done in weed science in the Asia and Pacific region. To be alone, we went to the East Kauai Methodist Church and used the kitchen as a meeting place. In the discussions which followed, we decided that what we would really like to do was to get a small group of knowledgeable persons - researchers, extension workers, industry scientists - somewhere in a key location (Fiji was one suggestion) to answer some of the following questions: (I) who are the weed workers in the Asian-Pacific area; (2) what are the major weeds and weed problems; (3) what are the research and development needs of the various countries; (4) what linkages are necessary or possible in dealing with the perceived needs?

Funding for this became a readily apparent need. We decided to approach East West Center to ascertain their interest. We made an appointment with Y. Baron Goto, Vice Chancellor of the East West Initiative for Technical Interchange. In our meeting with Baron we outlined what we hoped to accomplish and what we thought could be done to achieve this. Baron surprised us by readily agreeing that something should be done. He said something like this: 1) there should be such a meeting, 2) it should be larger than we asked for and should survey the Asian Pacific area, 3) it should be held in Hawaii, 4) the EWC-ITI would co-sponsor it with the College of Tropical Agriculture, 5) Horace Clay would act as his staff representative in planning it, and 6) he would ask us to begin to develop plans.

Later that evening, when Roman and I were seeing Bill off at the plane, we were enthusiastically searching for a theme for the meeting. We worked it out: "Weed Control Basic to Agriculture Development". Many steps followed. Baron sent Roman to Asia to seek out possible participants and to identify key participants. Roman and I asked Congressman Sparky Matsunaga to be our keynote speaker (he readily agreed). We decided to have 2 locations for the meeting; one week in Honolulu followed by another week in Kauai. Kauai was selected as the site for several field demonstrations and field trips..."

The meeting was a real joy. Many weed workers who had been toiling in isolation for the first time met other persons with similar interests. Surveys of important weeds of crops, of trained workers, and of existing weed science programs, etc. were conducted. The Proceedings was edited by Roman Romanowski, Don Plucknett and Horace Clay. Several chemical companies helped the University of Hawaii College of Tropical Agriculture and the East-West Center Institute to support its publication. On the last day of the Interchange, at the Prince Kuhio Hotel near Poipu on the island of Kauai, the Asian-Pacific Weed Science Society was proposed and organized. We met in a large tent on the lawn overlooking the blue Pacific. Here, the first officers were elected and given a mandate by the members to proceed with the development of what has become a major regional (and truly international) Weed Science Society.

We have been so fortunate to have good support from many sources, first of all the East-West Center which backed us and got us started and the companies have always been supportive and helpful. And we have had outstanding leadership from an energized, committed membership and individuals who caught the vision and built well beyond what Roman, Bill and I could have envisioned in that tiny little rural church kitchen in Kauai..."

(Donald Plucknett, Honolulu, Hawaii, Dec 2006)

Thus, Began Our Journey

As Don Plucknett's letter explained, the Society came into being following an "*Asian-Pacific Weed Control Interchange*", held during 12-22 June 1967 at the

East-West Center, University of Hawaii, in Hawaii. A group of 87 individuals, from 22 countries, participated at the inception meeting under the theme: "*Weed Control - Basic to Agriculture Development*".

On the last day, a Workshop recommended the formation of an organization: "…*to facilitate the interchange of current weed control information and promote research in Weed Science...*" A news release on 3 July 1967 by the East-West Center, after the first Conference stated: "*the Society will seek to stimulate research into how extensively weeds limit food production in the tropics, giving major attention to rice in Asia and to coconuts in the Pacific* ". The desired outcomes were to identify: (a) the weed workers in the Asian- Pacific region; (b) the major weeds and weed problems of the region; (c) the research and development needs of various countries in the region, and (d) the linkages necessary or possible in dealing with the perceived needs.

The credit for creating a professional society to help deal with the issue of weeds in the Asian-Pacific region must go to these three founding fathers – Bill Furtick, Donald Plucknett and Roman Romanowski Jr. and this first issue of the APWSS journal is an opportunity to honour their vision, enthusiasm and hard work. They deliberately encouraged scientific research on weed control, in the 'tropics', with most attention to rice and coconuts because weeds were roughly estimated to 'stifle' as much as 40% of production of these crops (APWSS, 1977). The primary motivations for founding the APWSS were further clarified by Bill Furtick at the Second APWSS Conference, in the Philippines, in 1969.

> *"…Weed Science suffers because weeds have been an integral part of agriculture from the beginning and their damage is less dramatic than that caused by insects and diseases. However, it is apparent that weed control is a pre-requisite for the development of modern agriculture, which is based on developing high yielding, high quality varieties that can produce their potential only under optimum fertility, water and freedom from pests. This means that without weed control, modern agriculture will end up under a canopy of weeds. It is the duty of the weed societies to get this story across to others in agriculture. It has often been possible for the representatives of industry to convince the farmer whose income is affected, while the professional agriculturist is oblivious to this basic importance of weed control. This cannot continue, but can only be changed by a planned effort…"* Furtick (1969)

Remembering Our Founders

As our forefathers imagined, the APWSS provided both the foundation and the coordination for the initial '*planned effort*' referred to by Furtick (1969). Clearly, as attested by the success of APWSS Conferences, weed scientists in the region felt they '*belonged*' to a worthwhile community, through knowledge-sharing.

The nascent APWSS also brought the 'science' of weed management to the attention of agriculture and land managers of the Asian-Pacific tropics, who had been largely by-standers in the evolution of the discipline. Until the late-1960s, major developments in weed science occurred mainly in USA and Western Europe (Chandrasena and Rao, 2017), where voices were also raising concerns over the environmental impacts of excessive use of herbicides (Harper, 1956; 1960) and pesticides (Carson, 1962). The founders envisaged the Society as a body that could also play a critical, peer evaluation role for scientific claims made about weeds, while also providing a conduit for information and networking, across the Asian-Pacific and other regions. In an ideal world, our founders also hoped the APWSS could provide a scientific perspective on weeds, agriculture, and environmental issues to governments in the region to help them formulate national policies.

In my view, our Society was founded at an optimistic time, when scientific research funding was more generous than at present, if one could convincingly argue a case, and weeds were one such topic. The world had just seen the great positive impacts of the 'green revolution' and there was genuine optimism that the poverty and malnutrition, which had tormented developing countries, could be solved by new hybrid crops and other technological advances in agriculture.

Throughout the 1960s, led by applied ecologists; Weed Science took shape as a serious, multi-disciplinary subject, moving away from being a 'herbicide-led' science (see Harper, 1960). The changes in the direction of the discipline appear to have motivated our pioneers to realize the rudimentary nature of the discipline in the Asian-Pacific region. Initially this led to extensive weed surveys in different countries, as the basis for planning more effective weed control. One of the most important outcomes of the initial decades was the collaboration between weed scientists, which resulted in the monumental treatise - '*The World's Worst*

Weeds' in two volumes written by a team led by Leroy Holm (Holm et al., 1977; 1979). These, and other lasting legacies of APWSS initiated the dialogue on weeds and efforts to increase food production, while protecting the environment, in our region.

Therefore, honouring the three APWSS founders, I provide below summaries of their inspirational careers in weed science. The accounts are based on information that can be obtained from the Internet - if readers are further interested.

Dr. Donald L. Plucknett

Plucknett triggered the formation of the APWSS through personal letters he sent to various people in the Asian-Pacific region. He served as the second General Secretary of the Society for 14 years (1969 - 1981), proving the dedication he had for making APWSS a success.

Plucknett was born in DeWitt, Nebraska, and served in the Army Field Artillery Corps during the Korean War. Stationed at the Schofield Barrack in Honolulu, he attained the rank of lieutenant. He received his B.Sc. in 1953 and a M.Sc. in Agronomy in 1957from the University of Nebraska and his Ph.D. in tropical soil science from the University of Hawaii in 1961, where he later served as Professor of Agronomy and Soil Science. He had an extensive career in tropical agriculture and worked at the University of Hawaii for 20 years (Shinhoster Lamb, 2007). While on loan from the University, he went to Washington, DC to head the Natural Resources Management Program of the US Agency for International Development (USAID) where he served as Chief of Soil and Water Management at the Technical Assistance Bureau (1973-1976); Deputy Executive Director of the Board for Food and Agricultural Development (1978-79); and Chief of Agriculture and Rural Development in the Asia Bureau (1979-80). In 1976, he received USAID's Superior Honour Award for work in in International Development. He also served on several National Academy of Sciences' study panels. Dr. Plucknett later joined the World Bank and also served as Scientific Advisor of the Consultative Group on International Agricultural Research (CGIAR) in Washington, DC, during 1980-83.

Plucknett was a Fellow of the American Society for Agronomy, Soil Science Society of America, Crop Science Society of America, American Association for the Advancement of Science and the Linnaean Society of London. He led a delegation of agricultural specialists to China, as part of a scholarly exchange program between the Committee on Scholarly Communication with the People's Republic of China (CSCPRC). The report of that visit (Plucknett and Beemer, 1981) is an in-depth analysis of vegetable farming systems in communes, research institutions, agricultural colleges, and universities in the major suburban vegetable production areas of northeast and southeast China. It documents essential elements of systems of vegetable production in China's journey toward local self-sufficiency in food. It is interesting to note that Dr. Roman Romanowski (see below) was a key figure in the delegation and that he wrote or co-authored several Chapters of the report. At a time when China was not easily accessible to visitations by foreign scientists, this report was influential in opening up Chinese agriculture to the rest of the world.

He wrote or edited 20 books and over 200 articles in his career. He was a co-author with Leroy Holm, Juan V. Pancho and James P. Herberger on *The World's Worst Weeds* in 1977 and 1979 (Holm et al., 1977; 1979) and "*Weeds of the Tropics*" which he wrote with D. F. Saiki. In June 1977. Dr. Plucknett's other major work was "*Genebanks and the World's Food"* (1987), co-authored with Nigel J. H. Smith. This book warned that the international decline of genetic diversity can produce record harvests but creates crops that are defenceless against nature's threats. In an interview to the Christian Science Monitor, in 1985, Plucknett clarified that: "…*the loss of genetic diversity, particularly in crop gene pools, may well be the single most serious environmental problem facing mankind*…" Using his position as an expert in world food matters, Plucknett advocated strongly for the conservation of genetic diversity in crops through "Genebanks", preserving a wide variety of seeds.

Towards the end of his career, Plucknett was the president of his own agricultural research and development firm, based in Annandale, Virginia. He enjoyed traveling, reading and writing on a wide range of subjects, especially genealogy. As recorded by *The Washington Post* (see Shinhoster Lamb, 2007), he also loved singing and performing music. In 1989, he published a book of poetry, "*The Roof Only Leaked When It Rained*," which recalled his days in Nebraska. He passed away on 3 Sep 2007 at the age of 75.

Dr. Roman R. Romanowski, Jr.

Roman Romanowski was an Extension Specialist in vegetable crops and Professor of Horticulture at Purdue University (WSSA, 1982). He obtained his Ph.D. in vegetable production in 1961 from Cornell

University, was and became a recognized a vegetable crops authority. During his stay at the University of Hawaii as Associate Professor of Horticulture (1961-1969) he founded the APWSS, together with Plucknett and Furtick. While at Hawaii, Roman made many contributions to solving tropical weed problems.

After joining Purdue University in 1969, he developed a program to serve the vegetable growing industries in Indiana, in recognition of which he received the Junior Extension Specialist Award in 1980 from the American Society for Horticultural Science. In 1977, Roman was part of the Plucknett-led US delegation to study vegetable farming systems in the People's Republic of China. He co-authored the "*Weed Research Methods Manual*" published by the Weed Science Society of America (WSSA) in 1971 and was elected a WSSA fellow in 1981. He passed away on 20 September 1981 after an extended illness, at 50 years of age.

Dr. William R. Furtick

Bill Furtick, Professor of Crop Science and Weed Science, at Oregon State University (OSU), was among the first weed scientists to pioneer international collaboration in weed research through a program, which began in 1966 as a joint venture between the USAID and OSU. The program was carried out through the International Plant Protection Center (IPPC) at OSU focusing on weed control in the tropics, initially in South America and then, in Southeast Asia. Historical records would show that that Drs. Furtick, Romanowski and Plucknett came together to plan the APWSS through these weed research collaborative programs between the OSU and the University of Hawaii. From OSU, Dr. Furtick went on to Washington, DC to serve in a senior and influential position at USAID.

Born in Salina, Kansas, Bill Furtick graduated from Kansas State University and received both his Master of Science (1952) and Ph.D. (1958) degrees from the OSU. Until 1971, he was Professor of Crop Science and Director of the IPCC. In 1971, the United Nations called upon him to set up an Agricultural Research Center in Taiwan. Later, he became the Director of the Plant Protection Division at the Food & Agriculture Organization (FAO) of the United Nations (UN) in Rome. He left the FAO to become the Dean of Agriculture and Human Resources at the University of Hawaii; then, moved to Washington, D.C. to become the Director for Food and Agriculture in the Bureau for Science and Technology within USAID (Zimdahl, 2010). In between, Bill periodically lived and developed programs in several countries, such as Egypt, Jordan, and Georgia. During his career, Bill has worked in or visited all but five countries in the world. He was the President of the Weed Science Society of America (WSSA) in 1966 when he was only 39 years old. He served as President of the Western Society of Weed Science in USA in 1962 and was a fellow of both Societies.

During his distinguished career, Bill Furtick was appreciated by many students and peers. In the view of his staff and students, "…*had more ideas before breakfast than anyone else has in a year*…" (quoted in the Sep 2007, WSSA *Newsletter*, p. 7). He was Guest of Honor at the 8th Annual British Weed Control Conference in Brighton, England; and was also awarded an invitational address and membership in the National Research Council (NRC), National Academy of Science. The Association of Western Agricultural Experiment Station Directors made him a Director Emeritus in recognition of his leadership and outstanding service to agricultural research in the Western Region and the United States. As noted by Zimdahl (2010), "…*throughout his Weed Science and administrative careers, Bill Furtick was an innovator of new weed management techniques and evaluation methods. He was, in the true sense of the words, a mover and shaker...*"

Founders' Dream: APWSS in the 21st Century

The launching of a new Journal is also an opportune moment to place our Society in the 21st Century and reflect on what lies ahead for our discipline. The APWSS now sits alongside several other august bodies, which deal with weeds. These include the *Weed Science Society of America* (WSSA), the *European Weed Research Society* (EWRS), the *Canadian Weed Science Society, Indian Society for Weed Science* (ISWS) and the *International Weed Science Society* (IWSS). Having identified deficits in the knowledge of weeds and their control in the tropical, largely developing countries, our founders capitalized on the optimism that characterized the 1960s era. With convincing arguments, which attracted donor funding, they began a journey to transfer knowledge on more effective weed management from the 'western' advanced economies to the Asian-Pacific region. Their dream was *to link Weed Science knowledge to practical action* using their insights about what worked and what did not.

Linking Weed Science Knowledge to Practical Action

It is well known that, in many developing countries in the Asia-Pacific region, there is a significant gap between the agricultural technology available to farmers, and what they can afford. Therefore, there is a responsibility for our Society to encourage the adoption of state-of-the-art approaches to managing weeds. Weed management programmes in the future must be re-aligned to maintain the balance between economic, social, and environmental concerns. This requires an analysis of the ecological, biological and physical factors within the entire landscape, because weeds are only one constraint on agricultural production because weeds are only one constraint on agricultural production, so we need to be mindful of other interactions as well.

Published literature and the vast collection of APWSS Proceedings indicate there is a good baseline of knowledge on weeds, weed issues, and weed management frameworks available in the Asian-Pacific region. The proceedings of the Society also indicate that there are wide differences in how weeds are managed between countries. The differences reflect not just economic disparities, and possibly, proportion of populations attaining higher levels of education, but also funding and priorities. For instance, poverty alleviation and food security are the highest priority in developing countries of the region, whereas developed economies are struggling with social issues like ageing populations and labour shortages, (e.g. Korea and Japan).

Land-clearing, de-forestation, soil erosion due to over development are common problems, as are other environmental concerns (i.e. pollution of waterways). Despite this, in all countries we find deficiencies in funding for on-ground weed control programmes and weed research. Australia and New Zealand are classic examples where funding for weed management has sharply declined over the past two decades, except perhaps for managing herbicide resistant weeds. The decline in funding has forced the community to implement major weed management programmes, with governmental agencies often taking only a ‘backroom’ managerial role.

No doubt all countries have made errors in introducing exotic plants where they did not exist before, for perceived benefits. In taking action to reduce this risk, Asia-Pacific countries can certainly benefit from the experience of the ‘islands’, of Australia and New Zealand, which have developed excellent ‘border protection’ policies and Weed Risk Assessment (WRA) frameworks, which have been globally adopted. Key long-term strategies that are likely to minimize the negative impacts of weeds in the Asian-Pacific region include the control? of species that can become weeds in different countries, or regions, through risk assessments and strict regulations of plant imports, biosecurity, and other prevention methods.

Education and Extension Services

Extension is one of the most important processes in Weed Science, since it informs the end user – usually, the farmer, about which weed control methods may be beneficial to increase production, while safeguarding the environment. However, farmers are not the only ones who need to be informed. Decision makers, such as politicians, administrators and the public also need to be accurately informed of the importance of managing weeds and the methods appropriate for the task. As John Swarbrick (1991), an APWSS stalwart suggested, successful extension requires that the receiver has confidence in the giver of that information. Whatever the discipline or topic, the extension officers need to have the right attitude, background, knowledge and culture to successfully transfer information to farmers or others. These considerations were front-of-mind matters for our founders. Training in weed science, at the level required, is crucial in the region. Several APWSS countries have been active in promoting such training of extension officers, as evident in the activities of our affiliated societies.

Weed science education and extension in the region clearly needs to promote the need to adapt technology to suit local conditions and practices. New herbicides or integrated weed management packages are unlikely to be adopted unless weed researchers and extension workers ensure that what is recommended is actually practicable ‘on the ground’, within the environmental, socio-cultural and economic conditions of farmers and non-farming communities in the region. The importance of local research and demonstration trials cannot be overstated to achieve longer-term success, and in many situations, adoption of a good weed control method will require innovation, to modify the available approaches.

Reviewing the APWSS literature, it is evident that agricultural practices in our region vary from highly industrialised to subsistence systems; and from extensive monocultures to small areas of shifting cultivation and mixed cropping. Some of the more productive systems require high-energy inputs (mechanical or chemical energy), while other systems continue to rely on human and animal power and low inputs with modest or low productivity. Production methods based on high-end technology, may not always be appropriate for agriculture in a good proportion of the Asian-Pacific countries. Farmers in the region often rely on governmental and non-governmental sources for information, advice, credit and support, because they cannot afford complex, external support systems. Sophisticated environmental monitoring systems; GIS-linked, web-based information systems for predictions of local weather, or instruments for measuring irrigation water availability are scarce in the APWSS region, except in the highly advanced economies (such as Australia, New Zealand, Japan and Korea). These present particular challenges in the region for promoting effective management systems in agriculture or in environmental protection.

Failure to realize the wide gulfs between existing production systems will lead to waste in all aspects of weed research, education and extension. The wide diversity of people and cultures in the Asian-Pacific region means that '*one-size fits all*' solutions will not work. Therefore, APWSS must promote research, which is local and appropriate. The process to do this well is by consultation and information exchange through existing or new networks. Fast-evolving technology allows scientists to connect with each other much more freely. Casting an eye on the future, as an over-arching regional Society, APWSS must continue to energize member countries and their local societies to engage with all stakeholders on weed-related matters.

A Final Word: Hope and Responsibility

As a final word, in paying due respect to our founding fathers, I ask – *have we fulfilled their dream*? I also ask - *what have we learnt from Weed Science in the past 50 years*? *Do we know why we have weeds*? *Do we know why they behave in the way they do*? *Are all weeds evil*? Through Weed Science, have we learnt how to be a sustainable society? Have we learnt how to be innovative, to protect our environment, to adapt to changes and at the same time, produce sufficient food for humans and animals?

As significant as the accomplishments have been, in my view, the full potential of Weed Science is yet to be realized in the Asian-Pacific region. Our science is not just about just weed control. The maturity of the discipline would help show the way in shaping and improving our management of all natural resources, not just agriculture. I find that the development of weed control practices over the past 50-60 years, promoted by APWSS, has resulted in major improvements in how we deal with weeds throughout the region. As weeds are an important component of agricultural systems, recent increases in crop yields, can be partially credited to improved management of weeds. In addition, all over the region, there appears to be more confidence in addressing weed-related issues in 2017 than in 1967. Yet, we know that Weed Science is the most poorly funded discipline within the broader area of crop protection.

Our primary goal in weed management should be the integration of the full gamut of tactics and techniques that can be used against weeds. Perhaps, a qualifier may be added – *do so, only when and where there is a significant problem with weed abundance*. Only then will the potential benefits of weed control be sustainably realized. To achieve this goal, we need a complete understanding of the ecological role of weeds; the relationship weeds have with crops, the thresholds at which they become problems (in agriculture), and their interactions with other plants (in natural ecosystems). Although much is known about these aspects, this knowledge is incomplete for major species, particularly, under new conditions caused by climate change.

Understanding weeds still lags a long way behind our inadequate attempts to control them. Also, globally, taxonomic studies on weeds stands out as a research area greatly in need of attention. We believe that our region can take the lead in recognizing the special attributes of these species, as important components of the earth's biological resources. Although success brings weeds *occasionally* into conflicts with humans, the corpus of Weed Science literature supports the viewpoint that *not all weeds are bad all the time*. Given this, we believe that human populations and societies in the Asian-Pacific Region will benefit by focusing on a more holistic weed management paradigm, which includes resolving conflicts with weeds amicably, and perhaps even co-existing with them. Instead of continuing an unsustainable war against weeds, perhaps a better approach for the region would be to train the next generation of weed scientists to develop a *healthier attitude towards weeds*; recognize them as highly successful biological resources, rather than enemies, and manage them to the situation.

The history of Weed Science, so well documented elsewhere, acknowledges that weed occurrence is inevitable where human habitation and disturbances continue, and there is no simple remedy for the problem of weed persistence in its many manifestations (Timmons et al., 2005; Zimdahl, 2010), However, *weeds are a symptom of inappropriate land-use*; for instance, over-exploitation of land for various forms of agriculture, conversion of grassland ecosystems for pasture, land-clearing for human settlements and linear infrastructure, such as rail and road, and other human-caused disturbances. The more we understand this, the better we will be at planning how to manage plants that thrive under such disturbances. This, should be the primary focus of APWSS, going forward, in the 21st Century.

When seen through a broader lens, weeds can be a *powerful tool* to understand Nature and the interrelationships between organisms (all plants, including weeds; and all animals, including humans) and the environment. We now live in a world, separated so much from Nature, by our busy lives and aspirations, and confusion, through the pace of technology change. Perhaps, enjoying a moment with weeds, which thrive in inhospitable environments, will open our eyes. This understanding may also lead us to respond more effectively to some of the major challenges we face today: a burgeoning population; poverty; inadequate energy and food; negative impacts from over-exploitation of resources; pollution and other forms of environmental degradation. *Weeds themselves cannot alone be blamed for our inability to produce enough food; to reduce poverty or prevent the degradation of our environment*.

As I look back, the noble vision, which inspired our founders, remains unabated after six decades. The remarkable contribution of APWSS Conferences to Weed Science attests to this. Redeeming the discipline, in a practical sense, across the Asian-Pacific and possibly, influencing the broader region, must continue to be our primary goal, while making suitable adjustments of direction to take up new challenges, such as the rapid development of herbicide-resistance in weeds and the impacts of climate change on weed-related issues. Making the APWSS relevant in the 21st Century requires wider engagement with global movements of similar ilk, and networking, to share knowledge and experiences that will inspire the current and next generation of weed scientists. Given there is little consistency in approaches to dealing with weeds in the different member countries, developing a common agenda to educate and influence national policies must be a priority for the APWSS.

With the new Journal -*Weeds*, there is a heightened responsibility for the APWSS to apply the most stringent scientific rigour to all contributions in Weed Science, so evidence-based science can be promoted, backed by formulating and testing valid hypotheses with critical evaluations of data and information. Only then can appropriate national or regional weed management policies, based on solid science be developed. *Weeds* must also strive to promote responsible weed management. This means consideration of options and planning any deployment of tools *after* one has understood the most probable causes of why certain weeds are there in the first place and how they can be sustainably managed.

Due respect to the environment must be at the front of mind of those who do weed management planning. Our founders would agree that future generations of weed scientists should not be seduced by easy solutions or silver bullets. Most contributors to the new journal are likely to share a goal of achieving a sustainable future for the Asian-Pacific region and also, for the planet. Sustainability does not mean stasis. It means change and benefiting from change. A sustainable future is one that encourages innovative opportunity for people to learn and prosper; that incorporates responsibility to maintain and restore the biological diversity of nature; and that is based on a just, civil society. I am inclined to think that such an attitude, hope and responsibility, would be an important way in paying homage to our founders.

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PERSPECTIVE

Some Thoughts About Ethics for Agriculture

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Abstract

This paper is a result of a 50-year career in Weed Science, which evolved to study aspects of the moral philosophy and the ethics of Agriculture. It is in many ways a personal story, but it concludes with a plea for careful consideration of the ethics of the agricultural enterprise.

Keywords: Agriculture, ethics, philosophy, production, values, Weed Science

Introduction

After completing a Master of Science degree at Cornell University in 1966 and a Doctorate at Oregon State University in 1968, I arrived in Fort Collins, Colorado, to begin a new life as an Assistant Professor at the Colorado State University. The job required teaching a class — the Biology and Control of Weeds and doing research on soil persistence of herbicides and weed control in various agronomic crops. It was a long-desired opportunity and I knew I was ready.

In the beginning my life and university career resembled a mobile my wife gave me some years ago. It hangs in my home study and consists of a black paper circle and three dolphins made from red construction paper; each with a sharply contrasting black eye. Each dolphin hangs from a string at the end of a slim metal wire and they move alone or in unison, with frail elegance, grace, and beauty. One morning I walked into my study and found the supporting stick had come loose and the mobile had fallen to the floor. The frail elegance was gone. As I reflect on my weed science career, its direction, and on what I thought and knew as fact when I began, I know my career has resembled my mobile. I have come to seriously question the undergirding agricultural ethos which prizes maximum production at the lowest cost. Ethical consideration of the environmental and human effects of agricultural technology have been ignored.

In 1968, and for some years after, my life was fascinating, and everything moved forward in order and harmony. I knew the Vietnam War TET offensive occurred on January 31, Martin Luther King was assassinated on April 4, the My Lai massacre in Vietnam occurred on March 16, Robert F. Kennedy was assassinated on June 5, Tommie Smith and John Carlos gave the Black Power salute on October 16 at the Mexico Olympics, and Apollo 8 orbited the moon 10 times in late December 1968. Neil Armstrong and Buzz Aldrin walked on the moon on July 21, 1969. While these events were very important, they did not significantly affect my life or career.

Then, the stories and facts about the use of the herbicide 2,4,5-T (2,4,5-trichloro-phenoxy acetic acid) during the Vietnam War intervened. My career's supports began to loosen. I began to doubt if what I knew to be the foundational facts and supporting paradigm of my science were adequate. It was a crisis of faith; a crisis of faith in the conventional wisdom of my science. By 1950, 4.5 million kilograms of 2,4-D (2,4-dichloro phenoxy acetic acid) and 2,4,5-T were being applied annually in the United States (Wildavsky, 1985). In 1964, a study initiated by the National Cancer Institute suggested concern about the public safety of 2,4,5-T, a herbicide for woody rangeland brush control and forest weed control.

The National Cancer Institute study indicated the possibility that 2,4,5-T or one of its formulation's constituents might be a teratogen. Other allegations appeared over the next several years, many because an ester of 2,4,5-T was half of 'Agent Orange', a defoliant used in Vietnam. By 1970, there was enough evidence to halt military use of 2,4,5-T and for the US/Environmental Protection Agency (EPA) to initiate administrative proceedings to suspend its registration.

Throughout the 1970s increasing attention was given to the dioxin contaminant in 2,4,5-T. Extensive studies confirmed that a dioxin [1] was the teratogen in 2,4,5-T. In 1979, following a still controversial study of human miscarriages after 2,4,5-T had been used in forests in the Alsea basin of Oregon, the EPA issued an emergency suspension of all uses of 2,4,5-T for forestry, rights-of-way, and pastures. Public sentiment against the herbicide grew. The manufacturers and the EPA attempted to negotiate settlements to keep some uses. Discussions broke down in 1983 and all US uses were cancelled in 1985.

In 1971, I presented a paper titled - Human Experiments in Teratogenicity - in the ecology section of the Weed Science Society of America meeting. The philosophical supports of my elegant, ordered, satisfying professional life, began to crumble after that paper. The paper's major objective was to question the role Weed Scientists played and ought to play in an increasingly polluted world. I was troubled and asked my colleagues to help me think about under what conditions one could argue that 2,4,5-T or any other a pesticide is so necessary to achieve the desirable end of food production that any risk of human harm is acceptable.

I proposed that those who work with pesticides must ask and answer questions about whether means and ends are compatible. The paper argued that members of the public must feel they are participants in determining the way things are ordered. They must think they actually have, the power to choose. To make sense of choosing and participation real, people must have the evidence required to judge possible alternatives and outcomes. People must also have, beyond the evidence, a sense of Agriculture's goals that serve as a context into which particular judgements are fitted. Some senior colleagues spoke to me after the paper to tell me how wrong I was.

The essence of the rather unpleasant encounter was that they wanted to know why I was so eager to bite the hand that fed me and much of the rest of the world. Their comments assured me that something was wrong, but it was something wrong with me and my thinking. In my colleague's view, there was nothing wrong with Agriculture, weed science, or with herbicides. They believed that weed scientists should continue the scientifically responsible quest for the wise use of federally approved herbicides. I knew something was wrong but wasn't able to define it well, and I was beginning to doubt that the unquestioned development of technology for Agriculture was *a priori* good. A 1972 paper (Zimdahl, 1972) elaborated my oral presentation and continued the quest to decide what I thought and to see if anyone cared. The issues didn't go away. I continued to read and think and tried to learn more about the issues when I wasn't doing the teaching and research my job required.

A second paper (Zimdahl 1978) was published later in the same journal. It included two fundamental propositions.

1. Some species are pests and it is necessary to control their populations to produce food; and
2. Pesticides are the primary means to control pests, but there may be an unnecessary dependence on them.

The paper argued that special knowledge and the highly trained mind produce their own limitations, which frequently results in an inability or reluctance to accept views from outside the discipline owing to unquestioning acceptance of the discipline's conclusions; its current paradigm. After doing research and teaching for 20 years and making another attempt to clarify my thoughts (Zimdahl, 1991), it was time to reflect on what I had learned and plan my future. This led to increased focus on the values and ethics of Agriculture and required learning new ways of thinking. Exploring the ethical foundation of a science that had been my professional life was the task. Such decisions don't come without personal and financial costs. The personal costs have included loss of colleagues and friends who don't understand and assume the worst. In the minds of many, I was

[1] There are several dioxins. The dominant teratogenic molecule in 2,4,5-T was 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

still biting the hand that feeds me. The costs also included the intellectual difficulty of venturing into philosophy—a new, unknown area. The financial cost was because ethical reflection does not provide opportunities for research grants.

Agricultural scientists have always been enthusiastic in their work and ambition for the future. However, they have lacked an understanding of the need for an ethical foundation of Agriculture. They have not been interested in exploring and applying ethical considerations to their work. The central norm, the primary moral stance of agricultural science is that the research that is done should benefit humanity by aiding the production of food and fibre. Agriculture's technology has been the primary moving force behind many social changes. It is one of many production activities that takes pride in reducing its labour force. What becomes of the people displaced is someone else's problem.

I am puzzled by the new directions of Agricultural Science. Predictions about the future by agricultural scientists, say that it is good, essential, and going to get better. When I was a student, I don't recall hearing the word sustainable, and the environment was acknowledged, but not considered endangered. Genetic engineering was unknown. All of these are now powerful ideas with powerful constituencies, and they are affecting Agriculture's direction and its foundational ideas. It is important to acknowledge that Agriculture and its technology can affect and be affected by the development and direction of the greater society.

The aim of my ethical quest is not what many have assumed. Many think what I want is to tell them that they are ethically wrong because they have no ethical foundation for their work. They are wrong. It is not a matter of sorting things out to a final, definitive truth that a few understand, and others do not. The aim is to create a harmonious and mutually acceptable view among its practitioners from which to address existing and future ethical and value conflicts. Discussion of foundational values, of why we practice Agriculture as we do should become a central rather than peripheral or absent part of agricultural practice and education.

One of the important things I've learned is that the persistence of moral conflict, of value questions, is an inevitable and important part of the human condition. Engaging in the debate stimulates the full development of the intellect and of our concern for others and the environment. A fear, and perhaps a fact, is that if agricultural scientists do not begin to understand and shape the ethical base of their discipline, it will just evolve or be imposed by others. The apparent ethical foundation of Agriculture can be summarized in the following three points.

1. Those engaged in Agriculture are certain about the moral correctness, the goodness, of their activity.
2. The basis of that moral certainty (the supporting reasons) is not obvious to those who have it.
3. In fact, Agriculture's moral certainty is potentially harmful because it is unexamined by most of its practitioners.

My 2006 book, *Agriculture's Ethical Horizon*, deals with these important questions. It has, to my surprise and disappointment, drawn almost no comments. I hoped to make people think and thought some would comment, even if the comments were angry. In Agriculture, we have <u>assumed</u> that as long as our research and the resultant technology increased food production and availability, Agriculture and its practitioners were somehow exempt from negotiating and re-negotiating the moral bargain that is the foundation of the modern democratic state (Thompson 1989).

It is a moral good to feed people and Agriculture does that. Therefore, we assume that anyone who questions the morality of our acts or our technology simply doesn't understand the importance of Agriculture or the value of what has been accomplished. The results of our technology make us morally correct. Wendell Berry (2002), an American author and agricultural philosopher, points out the error of this common agricultural assumption.

Higher education has grown more scientific in its quest for knowledge. At the same time people in many countries have become more concerned about moral truths—absolute truths. A result is that societies are more polarized in their struggle to find political and existential truth (Yankelovich, 2005). It is also true that some areas of truth do not yield to scientific inquiry. Moral dilemmas are common in Agriculture and we need an ethical foundation to help decide between two choices where each has strong supporting arguments. For example:

1. Should we increase agricultural production, to feed more people, regardless of the environmental or human harm the technology that creates the production causes?

2. Should we raise animals in confinement if it is harmful to the animals but makes meat cheaper for consumers?
3. Should we mine water from deep aquifers to maintain irrigated farms in dry areas?
4. Should we change production systems to decrease soil erosion?
5. Should we decrease nitrogen fertilizer use in the Mississippi basin to reduce the effects on fishing and ecological stability in the Gulf of Mexico hypoxic zone; one of the largest in the world? 2
6. Should family farms be protected and preserved or allowed to die because they are economically inefficient, that is, they can't make sufficient profit?
7. Should we give more or less food aid to developing countries?
8. Should we accept or reject agricultural biotechnology?
9. Should we reduce herbicide and other pesticide use in American Agriculture?

Each of these is a difficult moral dilemma for Agriculture. They are not just scientific questions. It is time, indeed past time, for all involved in Agriculture to think about and address the ethical dimensions of these and similar questions.

The next generation of Agriculture practitioners, scientists and teachers should be equipped with the intellectual tools required to guide decisions about Agriculture's existing and future ethical dilemmas (Chrispeels, 2004). Offering courses in agricultural ethics will not alone quickly increase the overall emphasis on ethical considerations within the agricultural community. But it will be an important recognition of the need for Agriculture to address its ethical dimensions and for the entire agricultural community to become engaged in the discussion (Zimdahl and Holtzer, 2018).

When one questions the value or wisdom of continued use of agricultural technology, many think the goal is to go back to 40 acres and a mule. Those who question the continued value of modern technology are not regarded as risk takers and without risk takers, progress will be inhibited. But it is not difficult to recognize that an increasing number of citizens question the safety of their food and the ethics of the system that produces it. Creating an ethical standard requires considering and perhaps changing fundamental values. It probably requires us to be counter-cultural and maybe even revolutionary. It requires taking some risks.

Conclusions

I conclude that we need to take public opinion seriously, which can be very difficult. A guiding principle to taking the public seriously is found in public engagement with honesty (Sterckx and MacMillan, 2006). The public's view of Agriculture and its technology is often one of tampering with nature that leads to bad results. This view does not stem solely from scientific ignorance and technological illiteracy. It is based more on distrust of science and scientists not on a misconception of scientific facts or irrationality (Shader-Frechette, 1991, p. 5).

Public disagreement with scientists on matters of risk is not irrational although the general public tends to be willing to assume less risk than scientists, who frequently operate with subjective values (Myskja, 2006). For example, a US National Academy of Sciences study (Edwards, 1987) reported that 60% of all herbicides then used in the U.S. can cause cancer in animals.

One must ask if the public's scientific values ought to dominate further discussion on the topic and if such discussion occurred. The question for all agricultural scientists is not whether we are better than we used to be. The question is, are we as good as we ought to be? Agricultural scientists are proud because of their contributions to agriculture's productive success. They know they are technically capable, and most assume that the technology's results (increased production) show that the agricultural enterprise is morally correct. But itis not wrong to suggest that only with respect for nature instead of opposition to it that our species will be able to remain in the world. A morally wrong act is disrespect for the limits of human capability, not just incorrect prediction of the harmful consequences of acts (Myskja, 2006).

[2] Nitrogen and phosphorus come from fertilizer in the farming states of the Mississippi River Valley. More than half of the fertilizer applied each year ends up in the atmosphere or local waterways releasing 2.1 billion tons of carbon dioxide equivalent in the form of nitrous oxide. (Worldwatch, May/June 2008, p. 4). One third of US greenhouse gas emissions come from Agriculture (Gilbert, 2012).

A value judgment of merit, or worth (Scriven 1994) is often thought of as subjective, biased, and unreliable. Positivists and scientific analysts alike believe that the words ***is*** and ***ought*** to belong to different worlds. The belief is that sentences constructed with ***is*** usually have verifiable meanings whereas sentences constructed with ***ought*** never have (Bronowski 1965, p. 56). For example: Plant leaves are green because chlorophyll, the dominant pigment, **is** green. Sentences with **ought** are possible because we have the ability to reason. We ought to do what there are the best reasons for doing. For example: We ought to always be kind to children.

In science we accumulate observations and evidence that bear upon judgments and thus increase the probability of statements to the point where they become accepted beyond a reasonable doubt. The scientist is never absolutely certain because there always is or should be a healthy scientific skepticism that says: Criticism is always legitimate, no one has the final say, and no one has personal authority (Rauch 1993, p. 46). Science would not be science if it could not make and adequately support value judgements. Agricultural scientists make value judgements regularly [It is good to use herbicide X in the weed management system for crop Y because good results (higher yield, improved quality, lower costs) will be achieved]. Agricultural scientists also make moral judgements. For example, it is not uncommon to find the conclusion that we ought to pursue transgenic technologies because they offer the best promise of feeding a growing world population—a good thing to do. Those who oppose this view are often labelled as uninformed or simply ignorant. The dogma is not questioned, it is accepted.

Science is an activity that evaluates means to ends and the ends. But many claim that science does not make moral judgments or claims about ultimate value (Scriven 1994). That, I suggest, is false. We need the best scientists and the best philosophers to justify the basic value positions of science and to create an appropriate ethical standard for our science.

Ethical matters (the rightness or wrongness of actions) have always been implicit in Agriculture but they have not been emphasized or given a dominant role in decision making in agricultural education, industry, or research (Burkhardt et al. 2005). Agricultural practice has regularly raised "questions about values, priorities, practices, and policies" (Burkhardt et al., 2005). Few decisions in Agriculture are purely scientific or purely ethical. They are complex with scientific, economic, social, political, legal, and moral dimensions.

All dimensions must receive proper attention. Ignoring the ethics of what we do reflects the view that Agricultural Science is value-free, and ethics are simply personal. Omitting ethics from our science reflects the dominant, but now largely discredited view that values and value-judgments are contrary, to the practice of science (Burkhardt et al., 2005). It ignores the fact that the public is tracking us, they are good at what they do, and they care about what they value and what they assume we value.

All societies and all cultures, including the scientific culture, have created a system of values. It arises from collective beliefs of what it means to be human, part of a society, and an understanding of and assumptions about the natural world, their fellow human beings, and the transcendent (Anonymous, 1991). Dominant cultures, including the scientific culture, have always claimed the universality of their beliefs—their values. The scientific culture has ignored making its values and the ethical foundation of its work explicit. It has thereby ignored the effects of its work and its implied values.

The idea that ethical reflection is important to Agriculture is relatively new. In the words of the American philosopher William James (1995, p. 76), "…*First, you know, a new theory is attacked as absurd; then it is admitted to be true, but obvious and insignificant; finally it is seen to be so important that its adversaries claimed that they themselves discovered it*..." The risk of being of taking the lead to develop an appropriate, defendable ethical position for Agriculture is small. My advice to all is: Try it, you might like it.

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PERSPECTIVE

Broadening the APWSS Horizon in the Asian-Pacific Region

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Abstract

The major challenge facing the Asian-Pacific Weed Scientists and land managers in the region is to develop the most effective and sustainable weed management approaches for all systems, including agriculture and natural land systems. Whatever weed management approach we develop must be sustainable, in both the short- and long-term and acceptable as safe for the community, wildlife, and the natural environment. Given my previous involvements with the APWSS, in this inaugural issue of the APWSS Journal, I wish to reflect upon how the Society may assist all member countries, particularly, those which are yet to be affiliated to the Society. We are challenged by the rapidly increasing human population in our region, food scarcity, some new weed problems, a changing climate and special issues, such as the development of herbicide resistance, as a result of overuse of herbicides and unsustainable farming practices. What options do we have to meet these challenges? I propose that APWSS must expand its involvement across the region, and to do so, requires a renewed effort to obtain funding from donors for more training, seminars, and conferences on weeds. As our founders expected, we must also develop a programme to assist various governments and agencies of different countries in identifying national needs on weed-related matters and solutions.

Keywords: Agriculture, Weed Science, Asian-Pacific region

Introduction

Today we are experiencing a rapid change in the development of science and its applications across all human endeavours. Scientific developments and progress during the past 40 years can be compared with those of the previous one hundred years, or possibly, even with the past five thousand years period. From now on, it is expected that another great scientific revolution is occurring in the coming ten to twenty-year period. Creative thinking and innovation are needed in all research areas that affect humanity. In this regard, how to utilize innovative technology in agriculture is fast becoming an important issue. For instance, drone and robot technologies can be used in seeding, spraying chemicals and harvesting, etc. in agriculture, and farmers demand smart farming. In the Asian-Pacific countries, how could we adjust to a rapidly changing environment of scientific technology? How could we go together or share with the most underdeveloped countries in our region?

During the five decades (1967-2017), in our region, we have benefited from being associated with the Asian-Pacific Weed Science Society (APWSS) for developing various options for weed control in crop production and management of landscapes and waterways, etc. These aspects have often been highlighted and discussed at successive APWSS Conferences and other international meetings. Many papers and books have been published disseminating this knowledge and sharing information with other Weed Scientists of our region, and beyond.

Detailed information on APWSS Conferences is available in the paper entitled 'Commemorating 50 years of the Asian-pacific Weed Science Society (1967-2017)' compiled by Aurora M. Baltazar (2017). A critical analysis of the APWSS Conferences, presentations, themes, and subjects is provided in Chapter 1 of the 50th Anniversary Celebratory Volume written by Nimal Chandrasena and A. N. Rao (2017). Additional information is also available in several reminiscences of the 50th Anniversary Celebratory Volume of APWSS 50th (APWSS, 2017).

In addition to the above, as APWSS passes more than five decades of its existence, I wish to reflect on some other activities, seminars, and conferences held in this region, which helped us to develop Weed Science in the region. These included several seminars, workshops and conferences supported by the Food & Agriculture Organization (FAO), International Rice Research Institute (IRRI), Food & Fertilizer Technology Centre in Taiwan and meetings of the Steering Committee for Weed Management for the Asia & the Pacific Region in 1990s, which was also established with support from the FAO. Particularly in case of Korea, the achievement of food self-sufficiency in 1977, through rice varietal improvement, made from crosses between Oryza sativa L. indica and japonca types of rice, accelerated the adoption of improved weed control technology, particularly, with the adoption of integrated practices that achieved highly effective weed control, combined with herbicides.

Widespread use of herbicides was common in the USA and Europe in the 1950s and 1960s. But herbicides were not commonly used in most South-Asian and South-East Asian countries, until much later. Also, the focus of Weed Science, at that time, was mostly on temperate weeds. There was not much attention paid to tropical weeds until the major weed book – '*The World's Worst Weeds'* was produced by LeRoy Holm et al. It is, perhaps, here, that the formation of the APWSS in 1967 (Chandrasena and Rao, 2017) had a significant impact. The Society's early years focused on promoting weed surveys in different countries and intensive studies of weeds, including weed biology, weed ecology, ecophysiology, and taxonomy, as a prelude to developing effective weed control solutions.

However, in the 1970s herbicides became an essential component for weed control in all crops in the region, including all cereals, vegetables, pulses fruit orchards and plantation crops, such as rubber, tea, and coconut. Economic developments of each of the countries of the region might be correlated with the choice of method(s) to control weeds in the field, and thereby, increased food production. It is evident that farmers select methods that provide the desired, high degree of weed control at the lowest cost, and therefore, the input prices are an essential factor determining input uses (De Datta et al., 1982).

Throughout the 1970s and 1980s, a range of herbicides and novel formulations (such as mixtures) were introduced at reasonably affordable prices for the major crops in the region. In my opinion, the APWSS biennial Conferences were a vital forum for the exchange of Weed Science information, including herbicides. These and other integrated practices, led to the adoption of effective weed control in cropping systems, resulting in significantly increased food production and poverty alleviation in the region. As Moody (1985) suggested, based on the likely impact in a highly populated region, the APWSS biennial Conference ranked among the most important Weed Science Conferences in the world.

National Weed Science Societies affiliated with APWSS

In 2017, Baltazar (2017) pointed out that 18 national Weed Science Societies in the Asian-Pacific region were closely affiliated with the APWSS (see Table 1 with some additional notes). Baltazar (2017) categorized any national or regional Weed Science Society, which actively participates in APWSS activities as an affiliate of APWSS.

On reflection, I am convinced that the Society has played a crucial role in connecting a vast number of Weed Scientists, from a large number of countries, over more than half-a-century period, by providing a vibrant forum for the exchange of Weed Science related information and ideas. In an address to the Society, Rahman et al. (2012) expressed the same view. However, Adkins (2017) emphasized that we are now entering a period of unprecedented population growth, one of rapid climate change, and the rapid emergence of several new and significant weeds. These weed problems and weed-related issues need to be managed while balancing the growing demand for agricultural products and the need for biodiversity conservation and environmental protection in the years to come. What about the many unaffiliated countries to APWSS in Asian-Pacific region? Frankly, we do not know what is happening concerning Weed Science in those countries.

The presence of a number of unaffiliated countries to APWSS in Asian-Pacific region means that the Weed Science community is not well yet organized or have not been very active in these countries. The main question, then, I wish to ask is: How could we share the advancements of weed management technologies and help organize national Weed Science Society in unaffiliated countries to APWSS in Asian-Pacific region?

Table 1. National Weed Science Societies affiliated with APWSS (Source: Baltazar, 2017)

Name of Society	Country	Year Founded	Year Affiliated with APWSS
Weed Science Society of Indonesia	Indonesia	1971	1971
Weed Science Society of America	USA	1956	1973
New Zealand Plant Protection Society	New Zealand	1948	1973
Weed Science Society of Japan	Japan	1962	1973
Indian Society of Weed Science	India	1968	1973
Council of Australian Weed Societies*	Australia	1976*	1973
Weed Science Society of China	China	1981	1989
Korean Society of Weed Science	South Korea	1981	1989
Malaysian Plant Protection Society	Malaysia	1976	1989
Pakistan Weed Science Society	Pakistan	1987	1989
Weed Science Society of the Philippines	Philippines	1968	1989
Weed Science Society of the Republic of China	China (Taiwan)	1980	1989
Weed Science Society of Thailand	Thailand	1971	1989
Weed Science Society of Vietnam	Vietnam	1997	1997
Weed Science Society of Sri Lanka	Sri Lanka	1990	1999
Weed Science Society of Bangladesh	Bangladesh	2008	2008
Weed Science Society of Israel	Israel	1964	2015
Iranian Society of Weed Science	Iran	1950	2015

* **Notes:** Under the auspices of the Australian Agricultural Council, the first Weed Science Society in Australia - the *Weed Society of New South Wales*, was formed in 1966, a year before APWSS was formed (Chandrasena and Rao, 2017). The Australian Council of Weed Science Societies (CAWSS) was formed in 1976; however, its members who attended the early APWSS Conferences may have been affiliated with APWSS in 1973. In 2003, the name changed to Council of Australian Wedd Societies (CAWS).

The Asian-Pacific region is rather loosely defined. The following is intended to only assist readers and is not an exhaustive listing of countries. Major countries that are not yet affiliated to APWSS, which spring to mind include: Myanmar, Laos, Cambodia and Mongolia and are several Melanesian countries (Fiji, Papua New Guinea, Solomon Islands and Vanavatu). In addition, other independent nations in Polynesia (Samoa, Tonga) and Micronesia (Micronesia, Marshall Islands, Palau, Nauru) are not affiliated. As the APWSS is already affiliated with Weed Science Societies in Iran and Israel, which are considered part of the Asian-Pacific region, it can attract several other countries west of Pakistan, which, among others, would include Afghanistan, Turkey, Iraq, Lebanon, Jordan and Syria.

Why National Societies are important

Weed Science Societies that have been formed in many developing and developed countries, stimulate dialogue and cooperation among the many non-specialists and the relatively few specialists directly working to control weeds (Burrill, 1982). The societies in their respective countries, have the responsibility of organizing local, national or regional conferences, to stimulate discussion on the progress made in weed control in their own country and establish linkages to other parts of the world. This objective requires vision, and a commitment to a good cause. Having a global or regional outlook is critically important because weeds are spread by worldwide trade and traffic. Nor do weeds respect national borders.

In Burrill's opinion, the organization and management of a professional society is something that requires little prior experience, but it needs a few highly committed people. A Society, such as the APWSS, is an organized group of people, joined by a common interest. In our case, what binds us is the interest in scientific inquiries on weeds, and ultimately, the effective management of weeds for the benefit of farmers, the society at large, and the environment. Organizing a dedicated group in developing countries is difficult because it needs a significant number of trained specialists who are committed to the task and financial resources, as well as governmental and industry support (Nimal Chandrasena, *pers. comm*., June 2019).

The proportion of the contribution of agriculture to a country's economy is also an essential factor. If this portion is small, there is less interest in forming a professional body that represents a significant obstacle (such as weeds) to managing a country's agriculture. In some countries in our region, such as Australia, India, Indonesia, Japan, Malaysia, Philippines, Thailand, and Vietnam, there is significant interest in investing money in developing their workforces, to support well-established and quite advanced agricultural production bases. In the most advanced and technology or mining-dominated economies, such as USA, Australia, Japan, and South Korea, the percent contribution of agriculture to the country's gross domestic product (GDP) could be as low as 1.0% (USA) or relatively low figures (2-4%). In sharp contrast, in some developing countries, such as Bangladesh, Pakistan, and Indonesia, this figure is quite high (about 20-25%).

A few countries in our region fall in between with about 8-13% contribution of agriculture to GDP (examples are Sri Lanka, Malaysia, Thailand). In my view, workforces, including Weed Scientists and related land managers, would benefit significantly by the knowledge-sharing and coordinated efforts that can be promoted, achieved and maintained through a Weed Society or a Plant Protection Society. The interest in individual countries can significantly vary, as we have witnessed in the APWSS, according to, among other factors, political stability, governance, and organizational maturity.

A few interested and highly committed people need to play an essential role in organizing a Weed Science Society at the beginning. Again, we have the examples of several founders of APWSS whose efforts have been well documented elsewhere (see Chandrasena and Rao, 2017; and the Special Editorial in this issue). It might be true for countries, which have not yet formed or organized a Weed Science Society, and which may be lacking such highly committed or interested people related to Weed Science. In my view, some countries might have only a few concerned weed scientists, but they may not be able to organize a dedicated, professional Weed Science Society, because they lack governmental and industry support and knowledge about the necessary process, which involves surveying interested stakeholders and gauging the public interest. In such situations, how could APWSS help to create the interest and train or develop highly committed people in countries that are currently unaffiliated to APWSS?

Approaches to assisting others

There are several approaches that I propose to help other countries and their Weed Scientists. The first one has to be the training of a selected group of people in the region's countries, which already have well-established Societies and weed Science programmes. This objective may take the shape of short- or long-training courses or degree programs. The other option might be the training of select participants 'on-the-spot', in their own countries and native environments, through well-planned seminars, workshops, and symposia held on a regional basis.

Thus far, international organizations, such as the Food and Agriculture Organization (FAO), have played significant roles directly in agricultural development in the world. In recent years, due to budget restrictions, the FAO has rolled back their involvement in many areas, including Weed Science. There is currently no dedicated Weed Science Principal Officer at the FAO. As shown by the FAO Website (FAO, 2019), the Plant Production and Protection Division (AGP) supports countries in the transition to sustainable crop production systems. AGP works with countries and a broad range of partners in developing and promoting agroecological approaches to sustainable crop production, building on ecosystem services while enhancing and protecting the underlying natural resource bases. Their current work appears to focus on areas, such as sustainable crop intensification, pest, and pesticide management systems; seeds and genetic resources; and more holistic ecosystem management. Weeds are almost 'hidden' inside the Biodiversity, Environment, and Ecosystem Themes.

While the areas and themes promoted by the FAO (2019) are important, in this scenario, unlike in the past, it has been difficult for the FAO to initiate a seminar, workshop or symposium, related to Weed Science. This deficiency leads to the question: Who can initiate or support these kinds of activities in the Asian-Pacific region? By not focussing on areas, such as weeds more directly, there is a significant risk for both agriculture and the environment in our region. To implement this objective, I suggest, first of all, the Executive Committee of APWSS has to play a role in helping to organize the formation of national Weed Science Societies in those countries that have no such body in Asian-pacific region. Second, it would be meaningful to survey how many countries are an unaffiliated member to APWSS. Third, it would be necessary to identify the right persons in those countries to be trained in Weed Science. Fourth, we must try to understand the situations in those countries that have resulted in little or no progress, although APWSS has existed for more than 50 years.

In the beginning, I suggest that an umbrella organization, such as the APWSS, should focus on the countries, which may, with a little help, be able to organize within their countries a national body to represent the Weed Science community. This task requires identifying governmental and industry stakeholders who are eager to participate in such a venture. Furthermore, for implementing this objective and approach, it would be meaningful to get help from many retired Weed Scientists in the Asian-Pacific Region who can voluntarily participate in this matter and help other scientists and countries.

Opportunities and Constraints

My experience is that it is rather difficult for some countries to obtain funds for organizing a national Weed Science Society. Many people believe that weeds are not of much importance, compared with insects or plant diseases in terms of crop damage or yield reductions.

Of course, I think, this may not be true in all circumstances of crop production. If one looked hard enough, we are more than likely to encounter new weeds and weed-related, new land management problems in the region. Some of these challenges were recently highlighted by Adkins (2017). Among the new threats he identified, with which I agree, are the following:

1. Weedy rice or red rice (*Oryza sativa* L.) - first noted in 1988, weedy rice has now become a challenging weed in rice production systems in several of the south, southeast, and eastern Asian countries; 'weedy' rice varieties have a shorter life span and a taller stature;
2. Parthenium weed (*Parthenium hysterophorus* L.), which inflicts losses in rangeland production, crop production and natural environment, in addition to causing human and animal diseases;
3. Mikania vine (*Mikania micrantha* Kunth. ex. H.B.K) - one of the most invasive plants worldwide, which has become a damaging weeds of the natural environment, and also a problem weed in plantation and field crops;
4. Global transfer of weeds by human-induced spread, due to internationalization; and
5. Development of herbicide-resistant weeds, as indicated by Ian Heap's website; there are currently 500 unique cases (species x site of action) of herbicide resistant weeds globally, with 256 species (149 dicotyledonous and 107 monocotyledonous plants). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 167 different herbicides. Herbicide resistant weeds have been reported in 93 crops in 70 countries (Heap, 2019). The number of new cases of herbicide resistance is increasing by 25% per year.

In countries, which do not have well-formed professional bodies, the above problems need to be identified and addressed without delay. We must help in this process by surveying how many countries in the region have not yet organized a national Weed Science Society in their countries. Once this information is known, it may be possible to help such countries to organize such a Society. Countries could be categorized into different tiers depending on the strengths of their organizational capacities and educational level of people who might be professionals in agriculture and related fields. As indicated in the above, the first-tier countries, which do not need any further assistance, because they are already very well established, could offer help to other neighbouring countries in achieving this objective.

JICA (Japan International Cooperation Agency) and KOICA (Korea International Cooperation Agency) are two donor sources that are committed to poverty alleviation in the region. In addition to those agencies, there may be other donors in other developed countries, such as Australia's AusAID, or international agencies, such as the FAO. Two or three unaffiliated countries could collaborate, recommended by the APWSS Executive, and propose how they could work together to improve weed management technology in their countries, through surveys of problem weeds, holding seminars, workshops or symposia, etc. These individual countries would need to have a coordinated approach, clear objectives, and seek funding from one or more of the donor agencies.

In my view, there is a great need to help such countries to prepare a concept paper to get fund from donor agencies. For implementing this purpose, retired weed scientists from universities and government organizations in the Asian-Pacific region may be able to play a role, particularly if they have the previous experience in conducting training, capacity building and human resource development in the Asian-Pacific region.

Conclusions

A half-century has passed after APWSS became established in 1967. Considering the passage of time, I have often wondered why the number of affiliated countries with APWSS is only 18. This fact implies that there might be a significant number of unaffiliated countries to APWSS in Asian-Pacific region. In those unaffiliated countries, we would like to know that there are weed scientists and other land management professionals who can organize themselves to form national Weed Science Societies.

To answer these questions, I propose that APWSS should take the initiative to form a research group under its Executive, to broaden and extend assistance to the unaffiliated countries. This initiative should start with a survey to establish how many countries have not yet formed a national Weed Science Society and how many weed scientists or agronomists are doing Weed Science work in these countries.

We must also gauge the interest of government agencies and organizations in those countries, which may not have very well-developed national policies on agriculture and the environment. This approach might be a kind of the right way to start a journey towards a "weed-literate" society from a "weed-illiterate" society in the Asian-Pacific region (Nimal Chandrasena, *pers. comm*., 10 June 2019).

Thus, in my view, we must help advanced weed control technologies to reach unaffiliated countries to APWSS in the Asian-Pacific Region finally. To implement a programme, such as this, we need to select and train a few interested and highly committed people in Weed Science in each selected country. Second, the funding required for carrying out a programme such as this should be obtained from international donor sources. A planned approach is needed for fundraising, and training of interested and highly committed people, who will eventually form an effective and useful, professional body, which can drive a national agenda in the countries, currently unaffiliated to the APWSS in this region.

At this moment, as we launch a new Journal, dedicated to weeds and Weed Science, APWSS is taking a significant step and expanding its contribution to knowledge-sharing and networking throughout the region. This initiative is a new development for the APWSS that our founders would deeply appreciate.

As the Society is now quite mature, having celebrated more than 50 years of its existence, my primary message is that APWSS should continue to expand its role in the region by casting a wider net. As I propose, this can be through organizing Conference, Workshops, Training Courses, or Seminars, which can focus on solving the immediate problems of developing countries that have not yet benefitted from the Society. Not to do so will put food production and environmental protection in those countries and the broader region at peril, as the population increases, and land becomes scarcer.

I am encouraged to hear from the APWSS officials (Nimal Chandrasena, *pers. comm.*, 15 June 2019) that efforts are underway to organize such events and also to provide additional training to the junior Weed Scientists who are allied to the Society.

By extending a helping hand to those countries not yet affiliated to our Society, we would be making a significant contribution to the noble objectives that led to the founding of the Society in 1969.

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I am grateful to Dr. Nimal Chandrasena, the Editor-in-Chief of the new APWSS '*Weeds*' Journal, for inviting me to provide this Perspective. He also scrutinized and thoughtfully reviewed this manuscript several times, providing useful insights and comments, particularly, regarding APWSS's history and its 50-year old journey. I also deeply appreciate discussions with him on this topic; his assistance with the references and help in formatting the manuscript.

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ORIGINAL RESEARCH

Taxonomy of *Echinochloa* (L.) P. Beauv (barnyard grass) in the Asian-Pacific Region: An Update

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Abstract

This paper provides a revised key to the identification of taxa of *Echinochloa* in the Asian-Pacific region, the result of many years' study of this important weedy genus, with an emphasis on the importance of association with the Asian-Pacific Weed Science Society. Descriptions of two new Indian species are included.

Key words: *Echinochloa*, barnyard grass, Asian-Pacific grasses

Introduction

The inauguration of the Asian-Pacific Weed Science Society (APWSS) at the Asian-Pacific Weed Control Interchange in 1967 coincided with the beginning of my serious interest in the taxonomy of *Echinochloa*. After a year in Japan in 1965 on a technical scholarship at the National Institute of Agricultural Sciences in Tokyo, where I learnt much about one form of *Echinochloa* now known as *E. oryzicola* (*tainubie* in Japan), I was keen to find out whether it occurred in Australia. This led me into a field of surprises.

Contrary to the belief held by grass botanists in Australia that all of our barnyard grasses were exotic, Australia did have a number of native species, as Dr Joyce Vickery—distinguished grass taxonomist of the National Herbarium of New South Wales (NSW)—and I found in our detailed studies of Australian and exotic collections. Only one of these had been noted as a weed in rice. In my annual report for 1966, in dealing with my studies on *Echinochloa*, I drew attention to the confused state of the taxonomy of the genus, noting that I was "…*in the process of trying to elucidate (with the help of plants grown from seed) some of the problems involved*…," which I expected would "…*take some time in view of a number of difficulties, not the least being the relative inaccessibility of the relevant literature…*"

In those days I was working in the Ecology Section of the Division of Plant Industry at the Commonwealth and Scientific Research Organisation (CSIRO) in Canberra, ACT, where I was encouraged in my work by the staff of the Herbarium, now included in the Australian National Herbarium (CANB). On my moving to the Faculty of Agriculture at the University of Sydney in 1969, I was able to continue my work in closer association with Dr. Vickery.

My first association with the APWSS was at the Fourth Conference held in 1973 at Rotorua, New Zealand, where I presented a paper, my first on *Echinochloa* in the Asian-Pacific region, and again met Japanese delegates, who I had first been introduced to in 1965 in Japan. Since then I have received help and suggestions from various members of the Society and from others in the countries it represents. Attending APWSS conferences has enabled me to collect *Echinochloa* in New Zealand, Japan, the Philippines, and India. Visits to herbaria in these countries as well as in St Petersburg (Leningrad), Europe and the United States have been of great benefit. Special collecting trips in the Philippines, Indonesia and Burma (Myanmar) have given me a good appreciation of the distribution and variation of the species. I must acknowledge, too, the great support I have had in Australia, especially in relation to travelling costs.

The main purpose of this paper is to describe two new annual species of *Echinochloa*, collected originally from India, and to also present a revised key to *Echinochloa* in the Asian-Pacific region.

My first key (Michael, 1983) was the first attempt to put the world members of the genus in proper focus; the second key (Michael, 1994) included only *Echinochloa* in China; and the third key (Michael, 2001), here revised, include species and varieties in the Asian-Pacific region. It is important for readers to absorb the contents of the notes in these three attempts as background to my new key. In this paper I have provided additional comments on only a few taxa. My recent publications on *Echinochloa* have included an account of the genus in North America north of Mexico (Michael, 2003) and in Australia (Simon et al. 2009).

A great inspiration has been the revised edition of studies on the natural history of *Echinochloa* (Yabuno and Yamaguchi, 2001). It would be good to have an English translation of this thoroughly satisfying book. Additional useful contributions to the taxonomy of *Echinochloa* are to be found in K-U Kim and Labrada (2003).

Two new annual species of *Echinochloa* from India

In the following two descriptions, I have used codes for the various herbaria mentioned. They are:

BM The Natural History Museum, London, UK

K Royal Botanic Gardens, Kew, UK

MO Missouri Botanic Gardens, St. Louis, Missouri, USA

NSW Royal Botanic Gardens & Domain Trust, Sydney, New South Wales, Australia

P Museum National d'Histoire Naturelle, Paris, France

US Smithsonian Institution, District of Columbia, Washington, USA

I am most grateful for the opportunities to visit these and other herbaria throughout the world. Without their help, my work on *Echinochloa* would have been impossible. The acronym KFP in the first description means the Karnataka Flora Project.

1. *Echinochloa mentiens* P.W. Michael

Description:

Annual grass of rice-fields, mimicking rice. Culms close, erect to 1.3 m tall with lower portions up to 10 mm thick. Leaf blades erect, strongly scabrid. Ligules sparingly, finely pubescent. Panicles narrow, linear with branches (racemes) appressed to the primary axis, up to 2.5 mm long and 7 mm wide with the internodes scarcely longer. The nodes of the primary axis of the panicles and the whole length of the branch rhachises bear numerous bristles (setae).

Spikelets are in pairs, congested from the base of the branches, often appearing to be in regular rows, ovate, rigidly cuspidate, around 3.5 mm long. Lower glume reaches to be about half the length of the spikelet. Mature caryopses brownish, 2.0-2.3 mm long. An image of the holotype, from the Kew herbarium catalogue, is reproduced in **Figure 1**.

Diagnosis:

Similar to *E. colona* (L.) Link but with more robust habit, racemes of the panicles broader and with abundant bristles, spikelets bigger and the mature caryopses brownish, not whitish. The quite common form of *E. colona* in wetland rice (Michael, 2001) with spikelets around 2.5 mm long and whitish caryopses is much less robust than *E. mentiens*.

Echinochloa frumentacea Link differs from *E. mentiens* in its panicles with spreading, curved racemes, often nodding at maturity. Spikelets are more swollen and caryopses are whitish. **Figure 2** provides images that can be compared.

Holotype:

(see Figure 1). India, Karnataka, Hassan District, Maranahalli, 15 km from Sakleshpur, on main road from Hassan to Mangalore. In rice-field, standing above the level of mature paddy. C. J. Saldanha, P. W. Michael and S. R. Ramesh. KFP 14236, 30 Nov 1981 (K); Image ID – K000245284.

Isotypes:

St. Joseph's College Herbarium, Bangalore, India; NSW, Australia.

The specific epithet '*mentiens*' implies both imitation and deception and is considered appropriate to describe a plant that mimics rice so closely.

Other rice mimics in the genus *Echinochloa* include *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi (syn. *E. glabrescens* Munro ex Hook f.) and the two, often misunderstood, taxa, *E. crus-galli* (L.) Beauv. var.

oryzoides (Ard.) Lindm. [(syn. *E. oryzoides* (Ard.) Fritsch and *E. phyllopogon* (Stapf) Koss)] and *E. oryzicola* (Vasing.) Vasing.

Distribution and other Specimens:

Known only from India. North-West India ex Herb. Ind. Or. Hook.fil. & Thomson, originally labelled *Oplismenus frumentaceus*, collected by T. Thomson, without precise location or date (P) but quite likely to have been collected in 1842-1847 (Hooker and Thomson, 1855).

Central India, Madhya Pradesh, Gwalior, ex BM, C. Maries, 1 Oct. 1890 (NSW)
South India, Karnataka, near Mangalore. Plants were collected by J. F. Metz (1819-1886) in 1853, named as *Oplismenus colonus* Kunth var. *pseudocolonus* ejusd. by C. F. F. Hochstetter (1787-1860) and distributed by R. F. Hohenacker (1819-1886). The publication of this new name has been long delayed because of doubts about the name *Panicum pseudocolonus* Roth, which had been applied by Hochstetter under the derived name *Oplismenus colonus* Kunth var. *pseudocolonus* ejusd.

The type of Roth's species was based on a collection of Benjamin Heyne (1770-1819), now believed to be lost (unpublished note by J. F. Veldkamp, 2003). Roth's brief diagnosis is insufficient to separate it from the somewhat bristly forms of *E. colona* commonly occurring in the tropics. Nor did Roth (1821) refer to the large spikelets, thus pointing along with other distinguishing features to the new species, *E. mentiens*, described here.

Specimens have been seen in P (Herb. Steudel, Herb. E. Drake del Castillo and Herb. Mus. P.). These specimens prompted me to ask Fr. C. J. Saldanha of St. Joseph's College, Bangalore, for help in a search for the plants fitting those old specimens. It was due to his great kindness that we were able to rediscover the plants in 1981. Hohenacker's distributed specimens have also been seen in K and BM, along with specimens of *E. colona* collected in the same region. Additional specimens from the location of the holotype – KFP 14237 - are to be found in St. Joseph's College Herbarium and NSW.

Echinochloa mentiens may have been introduced to Louisiana, USA. with rice. A photograph that appears to be of this plant, referred to as a variety of *E. crus-galli* and given the common name 'Baronet grass' was presented by Robert E. Williams in 1956, in '*The Rice Journal*' (see **Figure 3**). Unfortunately, I have not been able to locate the authentic specimens of the original plants discovered on the farm of Mr. Jules Baronet, in about 1920.

It is highly probable that *E. mentiens* has been derived at least in part from the very variable *E. colona* (L.) Link as a response to the hand-weeding of rice throughout its long period of cultivation in India. A form of *E. colona*, showing appressed panicle branches, with unusually setose rhachises, has been collected from Karnataka (Herbarium of St. Joseph's College, Bangalore, Hassan District, Arsikere – C. J. Saldanha 13746, 10 June 1969; Mysore District, Virajpet – S. R. Ramesh and P. Prakash, KFP 3119, 9 Oct 1978).

This form has also been collected as a rice-weed from Louisiana (south of Crowley, C. E. Chambliss July 1930 (US); Plants of Louisiana, St. Mary Parish, D. S & H. B. Corell 9432, 3 July 1938 (MO); Crowley Research Station, B. Cox, 23 Aug 1984 (NSW) – see **Figure 3**). These plants are called 'Baronet grass' (personal communication – J. B. Baker, 1989), suggesting that both *E. mentiens* and its supposed progenitors may have been introduced together to rice fields in Louisiana.

Further investigations are needed to find the current distribution of *E. mentiens* in India and, perhaps, to locate specimens, old or new, from Louisiana.

2. *Echinochloa trullata* P.W. Michael

Description:

Robust, tufted, annual to 150 mm tall, geniculate or horizontal at the base and rooting from lower nodes, becoming erect. Leaf sheaths glabrous, ligular area smooth, occasionally with tubercle-based bristles at the margins of blade or sheath. Leaf blades up to 45 cm long and 1.0 cm wide.

Panicles stiffly erect at length, exserted, 8.5 to 17 cm long, rarely longer, no greater in width than one quarter to one fifth of their length and narrower than the length of the longest raceme; the greatest width is at the tips of the lower one to four racemes, gradually narrowing upwards becoming ovate-triangular in outline (trullate or trowel-shaped). Racemes densely crowded with elliptical-ovate to ovate spikelets 2.5 to 3.5 mm long and 1.5 to 2.0 mm wide, often borne at right angles to racemes when mature. Glumes evenly rounded or truncate above the 1 to 2 mm long stipe-like base. Lower glume acute, one third to one half the length of the spikelet. Spikelets awnless (or rarely short-awned), falling very readily at maturity. Caryopses ovate to broadly ovate, 1.5 to 2.0 mm long and 1.2 to 1.5 mm wide, pale golden brown. Embryo two thirds the length of the caryopses. An image of the holotype, from the Kew herbarium catalogue, is reproduced in **Figure 4**.

Figure 1. An image of the holotype *Echinochloa mentiens* P. W. Michael from the Herbarium catalogue at Kew (url: http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000245284)

A fragment of *Echinochloa mentiens* P. W. Michael from the type collection | *Oplismenus frumentaceus* (Roxb.) Link * | *Echinochloa frumentacea* Link **

Figure 2. The new species - *Echinochloa mentiens* compared with old herbarium specimens of *E. frumentacea*

* Image from Muséum National d'Histoire Naturelle, Paris (France) (url: **https://science.mnhn.fr/institution/mnhn/collection/p/item/p02722638**)

** Image from the Herbarium catalogue at Kew (url: **http://www.kew.org/herbcatimg/632497.jpg**)

Figure 3. (Left) a scanned image of Baronet grass from Williams (1956); (Right) an image of a fragment of *E. colona* (L.) Link, called Baronet grass, collected by B. Cox at Crowley Research Station, Louisiana, 23 Aug 1984 (NSW)

Diagnosis:

Similar to *E. crus-galli* (L.) Beauv. var. *crus-galli*, but the panicle, rarely exceeding 17 cm, always stiffly erect, ovate-triangular, no greater in width than one quarter or one fifth of its length and narrower than the length of the longest raceme, with greatest width at the tips of the lower one to four racemes. Spikelets mostly awnless, 2.5 to 3.5 mm long, falling very readily at maturity. Lower glume one third to one half length of the spikelet.

Holotype:

India, Manipur State, Tetland Bay, Imphal. A. A. Bullock 748, 27 Oct. 1945. Scrub Typhus Research Herbarium, Sheet 1 of 2 (K); Damp grassland. Not very common. Tufted grass, culm at first horizontal, becoming erect. An image is available at K of the isotype (sheet 2 of 2) (ID K – 000245285).

Distribution and other Specimens:

India, Assam, ex Herb. Hort. Bot. Calcuttensis W. Griffiths (1810-1845), no precise locality or date (P).

India, Manipur State, Dehra Dun, N. L. Bor 17188, 2 Nov 1942. A grass in the political agent's (PA's) garden, alt. 610 m (K).

India, Manipur State, Kanglatongbi, A. A. Bullock 657, 7 Oct 1945, alt. 910 m. Common in oak scrub (K).

Pakistan, Rawalpindi, A. Rahman 24852, May 1950. By stream alt. 510 m.

Fiji, Koronivia Research Station, Naitasiri D. Kooriveibau L18247, 8 June 1971. In rice field, common in wet land (NSW).

Australia, New South Wales, Camden glasshouse, grown from seed from Fiji, P. W. Michael, 6 Feb 1973 (NSW).

Indonesia, Sumatra, Lampung Utara, Sumberjaya, P. W. Michael 6681, 5 April 1981. Coffee plantation in water (NSW).

Myanmar, Maymyo, P. W. Michael 25, 28 Oct 1982. Annual in upland rice field, alt. 1050 m (NSW).

Figure 4. An image of the holotype *Echinochloa trullata* P. W. Michael specimen from the Herbarium catalogue at Kew (url: **http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000245285**)

This species is poorly known and requires further investigation. It is clear, however, that its home is the Indian sub-continent and it would be surprising if it were not found to be widespread. The occurrences in Sumatra and Fiji are most likely explained by the migration of Indian peoples.

Dr. Joyce Vickery and I recognized this plant as an unusual *Echinochloa* among specimens from Kew, which we called the "Assam form". During the APWSS Conference at Hyderabad in 2015, Dr. Iswar Barua, from the Assam Agricultural University, India, showed me specimens that reminded me of the "Assam form". Dr. Hirohiko Morita, from Japan, has recently recognized it as a distinct form. These, in turn, have encourage me to describe it as a new species.

List of *Echinochloa* taxa in the Asian-Pacific region

Given below is an updated list of the *Echinochloa* taxa in the Asian-Pacific region, based on my studies and reviews. A revised key to the species is also provided overleaf.

World Tropics

E. colona (L.) Link

Eurasia

E. crus-galli (L.) Beauv. var. *crus-galli*

Asia (including South-East Asia, Indonesia, New Guinea & adjacent islands)

E. caudata Roshev.

E. crus-galli (L.) Beauv. var. *praticola* Ohwi.

E. crus-galli (L.) Beauv. var. *hispidula* (Retz.) Honda

E. crus-galli (L.) Beauv. var. *austro-japonensis* Ohwi

E .crus-galli (L.) Beauv. var. *formosensis* Ohwi

E. crus-galli (L.) Beauv. var. *persistens* Diao

E. crus-galli (L.) Beauv. var. *oryzoides* (Ard.) Lindm.

E. esculenta (A.Br.) Scholz

E. frumentacea Link

E. mentiens P.W. Michael

E. oryzicola (Vasing.) Vasing

E. picta (Koen.) P.W. Michael

E. stagnina (Retz.) Beauv.

E. trullata P.W. Michael

Australia

E. dietrichiana P.W. Michael

E. elliptica P.W. Michael et Vickery

E. inundata P.W. Michael et Vickery

E. kimberleyensis P.W. Michael et Vickery

E. lacunaria (F. Muell.) P.W. Michael et Vickery

E. macrandra P.W. Michael et Vickery

E. telmatophila P.W. Michael et Vickery

E. turneriana (Domin.) J.M. Black

Africa

E. pyramidalis (Lam.) Hitchc. et Chase

North America

E. muricata (Beauv.) Fernald var. *microstachya* Wiegand

South America

E. crus-pavonis (Kunth) Schult.

E. polystachya (Kunth) Hitchc.

Revised key to *Echinochloa* in the Asian-Pacific region

NB. Spikelet length measurements do not include awns

A. Annuals

1.	Spikelets 3-5 mm long.	2.
1.	Spikelets less than 3 mm or greater than 5 mm long.	18.
2.	Ligule a line of bristles or fine short cilia.	3.
2.	Ligule absent, or the ligular regions bearing a few cilia or fine pubescence.	4.
3.	Numerous long bristles at nodes of inflorescence. Panicle spindle-shaped, up to 15 cm long. Spikelets narrowly elliptical. Awns of lower lemma up to 30 mm long, of second glume up to 10 mm long.	*E. elliptica*
3.	No long bristles along main axis or branches of panicle. Panicle narrow, linear. Spikelets broadly ovate or ovate-elliptical.	*E. turneriana*
4.	Spikelets broadly ovate, crowded along the often incurved branches of the inflorescence. Fertile florets and caryopses markedly humped, so that the second glume often appears to be shorter than the spikelet. Mature fertile florets not easily deciduous.	5.
4.	Fertile floret and caryopses not markedly humped.	6.
5.	Spikelets brownish at maturity. Commonly awnless, sometimes awned. Caryopses brownish.	*E. esculenta*
5.	Spikelets pale green at maturity, awnless. Caryopses whitish.	*E. frumentacea*
6.	Essentially obligate weeds of rice or crop plants in rice fields. Close tufted erect habit. Greatly resemble rice before flowering.	7.
6.	Not obligate weeds of rice, but all growing in wet places and often occurring in rice. Plants more or less spreading at base.	11.
7.	Panicle narrowly linear with alternate branches up to 25 mm long pressed closely to the primary axis. Spikelets around 3.5 mm long, caryopses 2–2.3 mm long, brownish.	*E. mentiens*
7.	Panicles erect or nodding, branches not pressed closely to the primary axis.	8.
8.	Spikelets 3–4 mm long.	9.
8.	Spikelets 3.5–5 mm long.	10.
9.	Spikelets 3–3.5 mm long. Lower lemma convex, hard and shiny. Awnless or less often awned, occasionally found on banks and fallow land.	*E. crus-galli* var. *formosensis*
9.	Spikelets 3–4 mm long, persistent, lower glume 0.22 length of spikelet. Leaf sheaths glabrous.	*E. crus-galli* var*. persistens*
10.	Spikelets broadly ovate to ovate. Inflorescence hanging almost horizontal at maturity. Spikelets nearly always awned. Awns sometimes as long as 50 mm. Lower glume 0.33–0.5 the length of spikelet. Collar region of leaves rarely with tufts of hairs. Caryopses ovate, embryo 0.7–0.8 the length of the caryopsis.	*E. crus-galli* var. *oryzoides*
10.	Spikelets ovate-elliptical. Inflorescence more or less erect at maturity. Spikelets awned or awnless. Lower glume 0.5–0.66 length of spikelet. Lower lemma often convex, hard, and shiny. Collar of leaves often with tufts of hairs. Caryopses oblong, embryo often 0.9 or more the length of the caryopses.	*E. oryzicola*

11.	Lemma and palea of fertile floret acute or acuminate with stiff tip. Panicle spreading, erect. Caryopses yellowish. Spikelets 3–3.5 mm.	*E. muricata* var. *microstachya*
11.	Lemma of fertile floret with withering tip sharply differentiated from the body of the lemma.	12.
12.	Panicle erect, ovate-triangular. Spikelets 2.5–3.5 mm long, crowded, mostly awnless, falling very readily at maturity.	*E. trullata*
12.	Panicle erect or nodding. Spikelets short- or long-awned, sometimes apparently awnless but, if so, there are always a few awned at the ends of the racemes.	13.
13.	Inflorescence strongly drooping at maturity, sometimes bending over as much as 180 degrees. Spikelets crowded with short, curved awns, mostly 3–10 mm long, but can be up to 15 mm long.	*E. crus-pavonis*
13.	Inflorescence often nodding but not strongly drooping at maturity.	14.
14.	Spikelets narrowly elliptical, up to 4.2 mm long. Awns of lower lemma up to 40 mm long. Awn on the second glume up to 7 mm long or longer. Bristles on spikelets not spreading. Leaf sheaths glabrous.	*E. telmatophila*
14.	Spikelets broadly ovate to elliptical, never narrowly elliptical, almost awnless, short- or long-awned.	15.
15.	Spikelets ovate or ovate-elliptical up to 5 mm long. Panicle linear, anthers 1 mm or more long.	16.
15.	Spikelets broadly ovate, ovate, or ovate-elliptical, 3–4 mm long. Long bristles abundant along main axis and branches of panicle. Panicles various, often pyramidal. Anthers generally less than 1 mm long.	17.
16.	Spikelets ovate, uniformly 3 mm with strongly spreading bristles up to 1 mm long. Long bristles prominent at point of attachment of racemes and along main axis. Panicles not becoming purplish.	*E. dietrichiana*
16.	Spikelets 3.5–5 mm long, with few or no bristles on main axis and/or branches of panicle.	*E. inundata*
17.	Spikelets broadly ovate or ovate. Awnless except at the ends of branches, short-awned or long-awned. Lower lemma flat, occasionally convex and shiny. Caryopses ovate. Panicles of variable length, more or less erect, often pyramidal, sometimes nodding, branches never obviously whorled. Long panicles, often with secondary branches on lower primary ones.	*E. crus-galli* var. *crus-galli*
17.	Spikelets ovate-elliptical, short or long awns. Caryopses more or less oblong. Panicles rarely pyramidal, erect or nodding, branches often whorled, more or less erect except for the lowermost ones.	*E. crus-galli* var. *hispidula*
18.	Spikelets 5 mm long or longer.	19.
18.	Spikelets 3 mm long or shorter.	22.
19.	Spikelets with awns up to 90 mm long. Anthers more than 1.5 mm long. Ligule a line of bristles or cilia.	20.
19.	Spikelets awnless or awned. Ligule absent, rarely a line of short cilia.	21.
20.	Anthers 1.5–2 mm long. Palea of lower floret about half the length of the lemma, sometimes absent. Lower floret neuter.	*E. kimberleyensis*
20.	Anthers 2–2.8 mm long. Palea of lower floret about length of lemma. Lower floret staminate.	*E. macrandra*

21.	Spikelets awnless, ovate, very finely pubescent. Main axis and short branches of inflorescence without bristles.	*E. lacunaria*
21.	Spikelets awned, ovate. Panicles hanging more or less horizontally at maturity. Awns up to 50 mm long. Obligate weed of rice.	*E. crus-galli* var. *oryzoides*
22.	Palea of lower floret absent of poorly developed. Spikelets dense, 1 mm broad, with awns up to 45 mm long. Panicles up to 20 cm long.	*E. caudata*
22.	Palea of lower floret fully developed.	23.
23.	Spikelets broadly ovate to ovate, awnless with panicle not more than about 15 cm long.	24.
23.	Spikelets ovate-elliptical to elliptical, usually with short awns. Inflorescence close, short with more or less erect branches.	*E. crus-galli* var. *austro-japonensis*
24.	Spikelets regularly arranged in rows. First glume regularly half the length of the spikelet. Caryopses whitish. Long bristles mostly absent from main axis and branches of inflorescence, occasionally a few scattered along the branches and clustered at the nodes.	*E. colona*
24.	Spikelets irregularly arranged. First glume about 0.33 length of spikelet. Caryopses brownish. Long bristles along main axis and branches of inflorescence present or absent.	*E. crus-galli* var. *praticola*

B. Perennials

All species have spikelets 3 mm or more long. Ligular bristles are always present and obvious, especially in the lower leaves. The lower floret is often staminate. Plants may have long creeping rhizomes and/or stolons and spongy floating stems. Sometimes the rhizomes are much shortened and thickened.

1.	Spikelets awnless or with short awns or long cusps. Spikelets crowded, very finely pubescent or for the most part glabrous, with short bristles and short awns or long cusps. Inflorescence often more than 40 cm long. Secondary branches often closely appressed to primary branches of inflorescence. Plant often up to 4 m tall with stout culms.	*E. pyramidalis*
1.	Spikelets awned, awns often long.	2.
2.	Spikelets elliptical or lanceolate, up to 5 mm long with bristles up to 1 mm long and with long, narrow lower glumes. Floating, often with long culms.	*E. stagnina*
2.	Spikelets awned, 3–4 mm long.	3.
3.	Spikelets lanceolate, 3.5–4 mm long, finely pubescent. Awns up to 15 mm long. Racemes up to 90 mm long. Culms stout, up to 3.6 m tall. Leaves up to 20 mm or more broad. Nodes and leaf sheaths glabrous. Ligular bristles obvious on all leaves.	*E. polystachya*
3.	Spikelets broadly ovate, 3–4 mm long with bristles 0.5 mm long. Awns up to 18 mm long, whitish. Panicles sometimes one-sided. Racemes 20–50 mm long. Culms generally less than 1 m. Leave often with transverse purplish bands. Ligular bristles often not on upper leaves.	*E. picta*

Notes on selected taxa

E. crus-galli var. *formosensis*

Echinochloa crus-galli var. *formosensis* is often referred to as *E. glabrescens* Munro ex Hook. f.

E. crus-galli var. *hispidula*

I believe that this is the appropriate name to use for *E. crus-galli* with non-pyramidal panicles, ovate-elliptical spikelets, usually prominently awned, common in sub-tropical areas and extending to Japan and southern China. There has been disagreement about the nature of *Panicum hispidulum* Retz., on which the name *E. crus-galli* var. *hispidula* is based. Ohwi (1962), who showed a picture of the Retzius specimen collected in India, believed it did not fit features of *tainubie* (now known as *E. oryzicola*).

The density of its spikelets, short inflorescence branches and the long fine awns can be fitted easily to occasional specimens from wet places in Japan.

E. crus-galli var. *persistens*

This was originally described by Diao (1988) as *E. persistentia* and later as *E. crus-galli* var. *persistentia* Diao (1990). Its very short lower glume is unusual in *Echinochloa*.

E. picta

Yamaguchi (2007), in his treatment of a hidden variety of barnyard grass (*E. crus-galli* var. *riukiuensis* Ohwi), provided a photograph (see below, **Figure 5**) showing plants with distant racemes, whitish awns and one-sided panicles, which made me think immediately of *E. picta.* It would not surprise me to find *E. picta* in the far southern Ryukyu Islands. I have collected it in the far north of Luzon in the Philippines.

E. polystachya

My *E. praestans* has been relegated to a synonym of *E. polystachya* (Simon et al., 2009). I had previously followed South American treatments, which considered *E. polystachya* and *E. spectabilis* Nees both as varieties of *E. polystachya*. I now believe they are separate species. The much more open panicles of *E. polystachya* with its long racemes distinguishes it from the more crowded inflorescence of *E. spectabilis* with its shorter racemes.

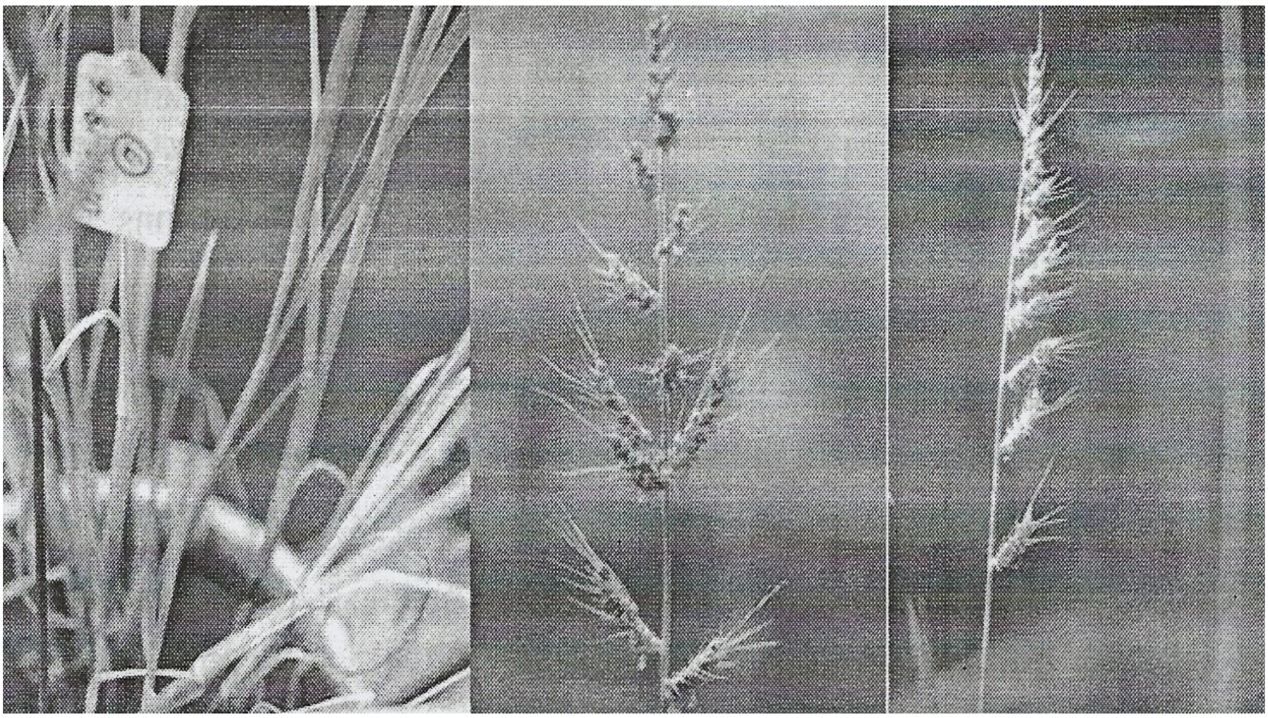

Figure 5. *E. crus-galli* var. *riukiuensis, r*eproduced from Plate 2 of Yamaguchi (2007). Regenerating young shoots (left) and panicles (centre and right)

Conclusions

It is to be hoped that readers will have the opportunity to test this key and to report any deficiencies. My hope is that some day more use will be made of the collections of *Echinochloa* in the National Herbarium of New South Wales, which now includes all of the species originally housed in the Faculty of Agriculture at the University of Sydney. It would be good if this paper were followed by up-to-date treatments of *Echinochloa* in the Americas (New World) and in Africa, including especially Madagascar. It might then be possible, with the help of pertinent molecular studies, to prepare a world key to replace my first attempt in Michael (1983).

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ORIGINAL RESEARCH

Biodegradation of topramezone by a *Trichoderma* Isolate in soil

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Abstract

Topramezone, a pyrazolone compound, has been introduced in many countries as a post-emergence herbicide. It inhibits 4-hydroxyphenylpyruvate dioxygenase (HPPD), a key enzyme in carotenoid pigment biosysnthesis, in susceptible plants, and can effectively control annual grasses and broadleaf weeds in maize (*Zea mays* L.), sweet corn (*Zea mays* convar. *Saccharata* var. *rugosa*) and popcorn (*Zea mays* var. *everta*). Topramezone is a highly persistent herbicide, which has high mobility in soil, posing a risk of leaching to ground and surface water. Despite its increasing use, not much is known about topramezone degradation and the potential impact of its persistence in the agricultural environment.

We investigated the interaction between the herbicide and soil microorganisms in topramezone-treated soil, in order to test its bio-remediation potential particularly by soil fungi, and to elucidate the possible degradation pathways. One microbial strain, capable of transforming topramezone, was isolated from soils treated with the herbicide and identified as a species of *Trichoderma*, a well-known, common soil organism. The isolate survived in the minimal broth, incorporated with topramezone, at a concentration of 1000 mg/L of the medium. In sterilized soil, spiked with the herbicide, the *Trichoderma* isolate degraded 85% of the applied topramezone within 30 days of incubation, which is much faster than the reported, standard half-life of the herbicide (about 120 days). Based on the eight breakdown products (I to VIII), which were identified by liquid chromatography-mass spectroscopy (LC-MS) analyses, we propose that the herbicide was degraded by the fungus through various biochemical reactions, viz. demethylation, desulfonylation followed by hydroxylation of the herbicides, alkyl hydroxylation, hydrolysis of the carbonyl group of ketone, methoxylation, and hetero ring hydroxylation. Our results add to previous research that *Trichoderma* species and its strains are capable of degrading some pesticides, including herbicides in soil. The degradation products identified strongly imply the presence of a substrate recognition mechanism and a corresponding metabolic response system in the *Trichoderma* isolate, which can effectively degrade topramezone in the agricultural soil.

Keywords: Biodegradation, Bioremediation, Herbicide, Topramezone, *Trichoderma* sp.

Introduction

Topramezone, a pyrazolone herbicide, has been introduced for crop protection in several countries, recently (Porter et al., 2005; Anonymous, 2006; Soltani et al., 2007). It is a selective, post-emergent herbicide, which controls broad-leaf weeds and several grasses in maize (*Zea mays* L.), sweet corn (*Zea mays* convar. *Saccharata* var. *rugosa*) and popcorn (*Zea mays* var. *everta*), at a low application rate of 25.2-33.6 g a.i./ha (Anonymous, 2006; Anonymous, 2018). The mode of action of topramezone is different from many other common herbicide groups, such as urea herbicides, sulfonyl ureas and imidazolinones, and carbamate herbicides. It acts by inhibiting the activity of the enzyme: 4-hydroxyphenylpyruvate dioxygenase (4-HPPD, EC 1.13.11.27), disrupting the biosynthesis of carotenoid pigments. It has been considered a strong choice for herbicide resistance management in some situations (Anonymous, 2006) because weeds of corn fields have developed resistance against triazines and ALS inhibiting herbicides in many countries, viz. Argentina, Austria, Belgium, Brazil, Bulagaria, Canada, Chile, China, Czech Republic, France, Germany, Italy, Mexico, New Zealand, Spain, Switzerland, and United States (Heap, 2019). Czech Republic, France, Germany, Italy, Mexico, New Zealand, Spain, Switzerland, and United States (Heap, 2019). In these countries, topramezone formulations have been registered as a post-emergent herbicide for maize, in recent times. The herbicide has also been registered in India, since 2015, for post-emergent weed control in maize.

The use of various topramezone formulations is increasing in maize-growing countries. However, not much is known of the degradation pathways or the impact of the herbicide in the agricultural environment, following applications. Topramezone is highly persistent in different soils. In the USA, in aerobic soil, its half-life has been determined to be more than 125 days (USEPA, 2005). It does not undergo hydrolysis or photolysis in soil and water, readily. The dissipation of this compound is largely dependent on sorption, over time. Moreover, topramezone has high mobility in soils and sediments, presenting a risk of leaching into ground and surface water (USEPA, 2005; Stipičević et al., 2016). There are no reports yet available on the biodegradation of topramezone in soil. Due to its higher chemical or photo-chemical stability in the environment, biodegradation by soil organisms is likely to be the natural way by which the herbicide concentrations may decrease in treated soil. Biodegradation is also considered as one of the most effective methods that might be manipulated to expedite the reduction of the concentrations of this herbicide from agricultural soil.

In previous studies, it has been observed that residues of many pesticides could be degraded by the augmentation of various species of the fungal genus *Trichoderma*, either in artificial media, or in soil. The genus *Trichoderma* is a large group of free-living fungi, commonly inhabiting soil and root ecosystems of plants. Some are well known to be beneficial microorganisms for the growth of crop plants. Some strains of *Trichoderma* control many soil-borne phytopathogenic fungi (Harman et al., 2004; Druzhinia et al., 2011), thereby, assisting crop plants to enhance root growth and development (Contreras-Cornejo et al., 2009), increasing nutrient uptake and inducing crop resistance to abiotic stresses (Yasmeen and Siddiqui, 2017).

Presently, the augmentation of effective *Trichoderma* strains in soil through various commercial formulations is gaining importance, both as a biocontrol agent, and a growth promoting agent. Augmentation of *Trichoderma* populations in soil is also useful for expediting the breakdown of pesticide residues in soil, as the genus and *Trichoderma* strains have long been recognized as effective bio-remediation agents in pesticide-contaminated soil. For instance, in some early studies, Kaufman and Blake (1973) found that the augmentation of *T. viride* in silty clay loam soil and in media resulted in an increased degradation and dehalogenation of a variety of pesticides, including chlorphenamidine, chlorpropham, dicryl, diuron, propanil, propachlor, propham and solan. In 1995, Smith observed the influence of different species of *Trichoderma* isolated from forest soil samples in the presence of persistent organochlorine contaminants. In their studies, two species of *Trichoderma, T. harzianum* and *T. viride*, degraded organochlorine pesticides *in vitro.* Both species of *Trichoderma* were also reported to be capable of degrading a broad range of other xenobiotics, including endosulfan, cyanide, phenanthrene, pyrene, and pentachlorophenol (Cserjesi, 1967; Katayama and Matsumura, 1993; Ravelet et al., 2000; Chavez-Gomez et al., 2003; Ezzi and Lynch, 2005).

Other studies have also shown that *T. viride* could degrade persistent pesticides, such as chlorpyrifos and photodieldrin (Tabet and Lichtenstein, 1976; Mukherjee and Gopal, 1996). More recently, Askar et al. (2007) reported that *T. viride* and *T. harzianum* degraded bromoxynil very efficiently, over 98% within 28 days after incubation in media. In addition, Abd-Alrahman et al. (2013) observed that *T. viride* could also degrade butachlor to the extent of 98% within 15 days. A marine-derived *Trichoderma* sp. (CBMAI 932) was also demonstrated to be capable of utilizing chlorpyrifos as a sole nutrient source by hydrolyzing it in distilled water (Alvarenga et al., 2015). The microbe was able to degrade 72% of the applied chlorpyrifos in media, and reduce the concentration of 3,5,6-trichloro-2-pyridinol, the metabolite formed by the enzymatic hydrolysis of chlorpyrifos. The cleavage of the sulfonyl urea bridge was suggested to take place through a pH dependent reaction. However, a strain of *Trichoderma* was found effective in cleaving the sulfonyl urea bridge enzymatically (Yadav and Choudury, 2014). The augmentation of *Trichoderma* sp. in soil, fortified with sulfosulfuron, a sulfonyl urea herbicide, led to the hydrolysis of sulfonyl urea bond with the formation of two degradation products, viz. 2-ethylsulfonyl imidazo {1,2-a} pyridine-3-sulfonamide and 2-amino-4,6-dimethoxypyrimidine. Thus, *Trichoderma* species clearly have the capacity to degrade pesticides of different chemical groups.

Given the above, the objectives of our study were to investigate topramezone degradation by *Trichoderma* sp., occurring in herbicide-treated soil, and the possible herbicide degradation pathways. Understanding the process of topramezone degradation in soil is important because it could lead to augmenting the organisms who are capable of causing the degradation of the herbicide, as a possible soil remediation option in the future.

Materials and Methods

Chemicals

An analytical grade sample of topramezone was obtained from the Sigma-Aldrich Corporation. Technical grade topramezone was prepared from the formulation, extracting it in dichloromethane, and further purification by repeated crystallization from chloroform and hexane, to a mass of very fine white powder, with a steady melting point of 221-222^{0}C. The purity of this technical topramezone was found to be 97.2% when compared with the analytical grade samples by HPLC analysis. All organic solvents and water were HPLC grade and were purchased from Merck India Ltd. Formic acid was acquired from Merck (Darmstadt, Germany).

Soil

Black (vertisol) soil was collected from the rhizosphere zones from topramezone-treated maize plots of the Experimental Farm, located at the ICAR-Directorate of Weed Research (DWR), Jabalpur. No residues of topramezone were found in the soil. To determine physico-chemical properties, the soil was gently crushed and passed through a 2-mm-mesh sieve. The physical texture of the sandy loam soil was: clay (<2 mm) 57%, silt (2-20 mm) 18%, sand (20-2000 mm) 25%, and organic carbon 0.96%. The soil was also chemically characterized as follows: pH 7.08, electrical conductivity (EC) 0.48 dS m^{-1}, and cation exchange capacity (CEC) 33.8 Cmol (p+) kg^{-1}.

Isolation of *Trichoderma* sp., a topramezone-degrading fungus

Soil, collected from the maize root rhizosphere, was fortified with topramezone at the rate of 50 mg per kg of soil. It was then incubated for one week at 30 ± 2^{0}C. The fungi that survived and persisted in the incubated soil were isolated on potato dextrose agar (PDA) plates. These fungi were screened further by incubating for an additional seven days in minimal PDA broth, containing a range of concentrations of topramezone, viz. 10, 50, and 100 mg per 100 mL of broth. The isolates that showed the highest capacity for the possible degradation of topramezone were screened further, based on their growth.

An isolate that showed promise was again inoculated on PDA plates and incubated at 30 ± 2^{0}C. After two days of incubation, the colony morphology of the isolate was studied. Finally, the fungus was characterized, based on its colony morphology and microscopy of spore and conidia structures, in the Pathology Laboratory of the ICAR-DWR Institute.

Degradation kinetic study

The rate of degradation of topramezone by the *Trichoderma* sp. isolate was examined in a sterile soil, which was obtained by autoclaving the soil at 121°C for 30 min. A Topramezone solution, in chloroform, was added to samples of sterilized soil at the rate of 10 mg per kg of soil. Samples (100 g) of treated soil were taken in Erlenmeyer flasks in triplicate for each day sampling. The soil of each flask was then inoculated with one mL of *Trichoderma* sp. spore suspension of a standard turbidity (10^6 spores/mL), measured by the spectrophotometric method. Flasks were then incubated in an aerobic condition, maintained at a temperature of 28 ± 2^{0}C. A set of three flasks containing topramezone-treated soil, without the inoculation with the *Trichoderma* isolate, was also kept under similar conditions, as a control. Samples were withdrawn from each treatment in triplicate, after 0, 5, 10, 20 and 30 days of incubation.

Soil samples of different days of incubation were extracted with ethyl acetate. The soil in each flask was mixed with 50 mL of HPLC grade ethyl acetate and 5 mL distilled water and agitated on a reciprocal shaker for 30 min at 150 rpm, followed by centrifugation at 3000 RPM for 15 minutes. The supernatant liquid was filtered through cellulose filter paper (Whatman Grade 1, 11 µm) to remove soil particles. The solid portion, deposited in the centrifuge tube, was again extracted twice by the same method. The combined, filtered solution was concentrated to 2-3 mL in a rotary vacuum evaporator at 40°C and made up to a suitable volume with the mobile phase for analysis by high-performance liquid chromatography (HPLC). For the rate kinetic study, the extracted samples were constituted in the mobile phase of a known volume and were further cleaned up through nylon-made membrane filters before HPLC analysis.

A Shimadzu (LC 8200AHT) isocratic HPLC system was used for the chromatographic separation and quantification of topramezone. The HPLC was equipped with an isocratic liquid pump and a photo diode array detector (SPD-M10A). A stainless-steel column of 250 mm length and 4.6 mm internal diameter packed with octadecyl silane, chemically bonded to porous silica particles of 5 µm diameter (SunFire C18, Waters Corporation), was used in the analysis of topramezone. The flow rate of the mobile phase (acetonitrile/water 65:35 v/v-orthophosphoric acid 0.1%) was maintained at 0.8 mL min^{-1}, and the detector wavelength was set at 250 nm for the monitoring of elution. Employing the above set of parameters, linearity was observed over a wide range of concentrations from 0.2 to 10 ppm. The developed chromatographic method resolved the peak for topramezone at a retention time of 2.83 min.

Isolation and characterization of degradation products

The incubated broth and soil samples, collected at different intervals, were partitioned with chloroform. The chloroform layers collected were dried over anhydrous sodium sulfate. A mixture of degradation products was obtained by evaporating the chloroform layers under low pressure in a rotary vacuum evaporator. The products were characterized by liquid chromatography-mass spectroscopy (LC-MS) with positive modes and tandem mass spectrometric (MS/MS) technique. For the structural elucidation of degraded products, an API 3200 Qtrap mass spectrometer of AB Sciex connected to Shimadzu Ultra Fast Liquid Chromatographic system was used.

Mass spectrometry analysis was carried out with electrospray ionization (ESI) in the positive mode (5500 eV) for each sample. The ion source temperature was set at 500°C. The nebulizer and heater gases were adjusted at 30 psi and 55 psi, respectively. Each sample was injected by an infusion device at the rate of 10 μLs^{-1}. The mass spectrum of each compound was developed after scanning the run at different collision energies obtained from the scanning of potential differences between two collision cells from 5 to 50 volt.

RESULTS

Characterization of the topramezone degrading microbe

The fungus, isolated from the soil of maize root rhizosphere, was initially characterized as a *Trichoderma* sp., based on its morphological features (**Figure 1**). It survived in the minimal broth with topramezone at 1000 mg/L of media (**Figure 2**).

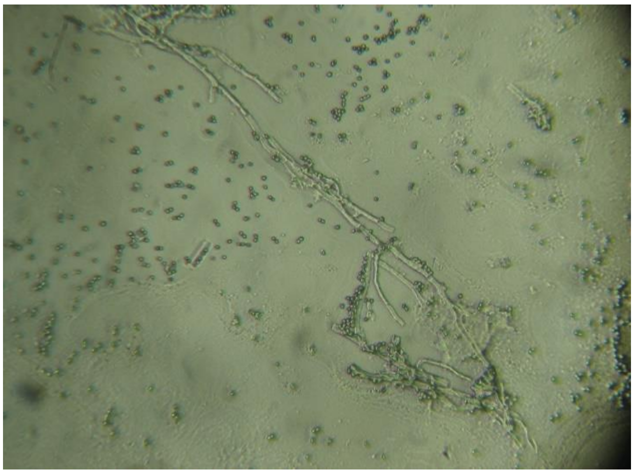

Figure 1. Microscopic characterization: spores, conidiophores and mycelia of the *Trichoderma* isolate

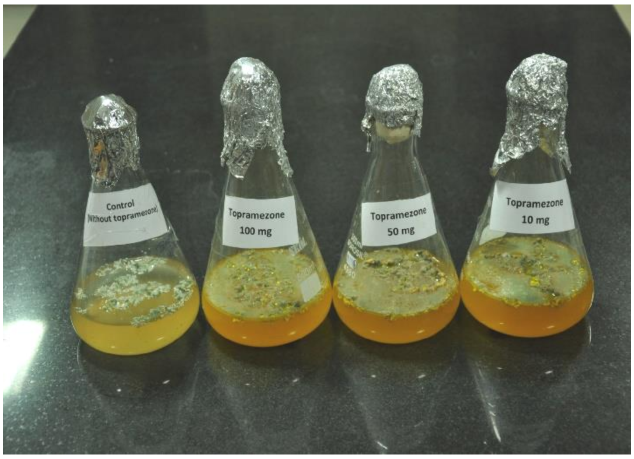

Figure 2. *Trichoderma* isolate growing at different concentrations of topramezone in minimal media

Colonies of the isolate were characteristically fast growing at the temperature of 25-30°C. During the growth period of the filamentous fungus, the colour of the colonies was initially white, which gradually changed to dull white or light green to yellowish green. The mycelia of the isolate were non-septate with a foot-cell. Conidiophores developed erectly inside the branches of hyphae and ended in a terminal, enlarged, ellipsoidal-to-spherical swelling.

The *Trichoderma* isolate is currently being characterized by molecular techniques; i.e. 16S rRNA analysis at the ICAR-Indian Institute of Horticulture Research (ICAR-IIHR), in Bangalore. We believe that the molecular analysis would aid in establishing its identity further in the near future.

The rate of biodegradation of topramezone in soil

The rate of degradation of topramezone in sterilized soil, incubated with the *Trichoderma* isolate, was determined by HPLC analysis of samples collected after different duration times of incubation. The isolate degraded 50% of the applied topramezone within 10 days of incubation and 85% of the herbicide disappeared within 30 days. Initially, the rate of degradation of the herbicide was high, before 10 days, after which the rate declined (**Figure 3**).

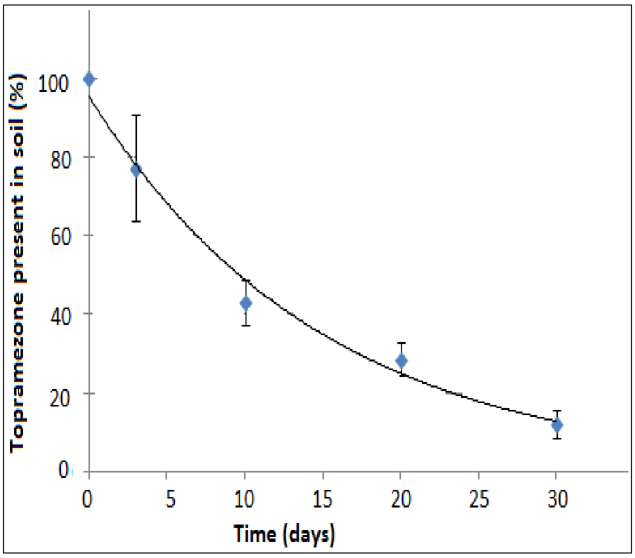

Figure3. Progressive degradation of topramezone in soil incubated with the *Trichoderma* isolate

Metabolism of topramezone by *Trichoderma* sp.

Fungi are known to degrade organic molecules using their own intracellular or extracellular enzymes, including hydrolytic enzymes, peroxidases, oxygenases, etc. (Van Eerd et al., 2003; Ortiz-Hernández et al., 2011). Although, we did not isolate any enzymes in our studies, it is possible to speculate that the isolated strain of *Trichoderma* sp. degraded topramezone both in the media and in soil by releasing intracellular or extracellular enzymes, which acted upon the herbicide, converting it into simpler forms of organic molecules.

Microorganisms are known to utilize these enzyme-driven degradation reactions to derive energy for their growth and maintenance or to detoxify the pesticide (Becker and Seagren, 2010).

In the present study, eight key metabolites produced during the degradation of topramezone by the *Trichoderma* isolate were confirmed by mass spectra and by comparisons with related literature. In media, topramezone was degraded to five major products: (I), (II), (III), (IV), and (VIII), the mass fragmentation pattern of which are given in **Figure 4**. Their chemical structures are given in **Figure 5**. The metabolites we identified were as follows:

I: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-mesylphenyl] (5-hydroxy-1-methyl-pyrazol-4-yl) methanone; II: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-hydroxy-*o*-tolyl] (5-hydroxy-1-methyl-pyrazol-4-yl) methanone; III: [3-(4,5-dihydro-1,2-oxazol-3-yl)-2-hydroxymethyl-4-hydroxyphenyl] (5-hydroxy-1-methyl-pyrazol-4-yl) methanone; IV: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-hydroxyphenyl] (5-hydroxy-1-methyl-pyrazol-4-yl) methanone; V: 2-(4,5-dihydro-1,2-isoxazol-3-yl)-4-hydroxytoluene; VI: 1-hydroxymethyl-5-hydroxy-4-pyrazolecarboxylic acid, VII: 1-methoxy-4-hydroxy-4,5-dihydroisoxazole, and VIII: 1-methoxy-4,5-dihydro-isoxazole].

Metabolites II, III and VIII were also found in the topramezone-fortified-soil incubated with the *Trichoderma* isolate. Other metabolites of topramezone isolated from the incubated soil were: (V), (VI), and (VII) (shown in **Figure 4** and **Figure 5**).

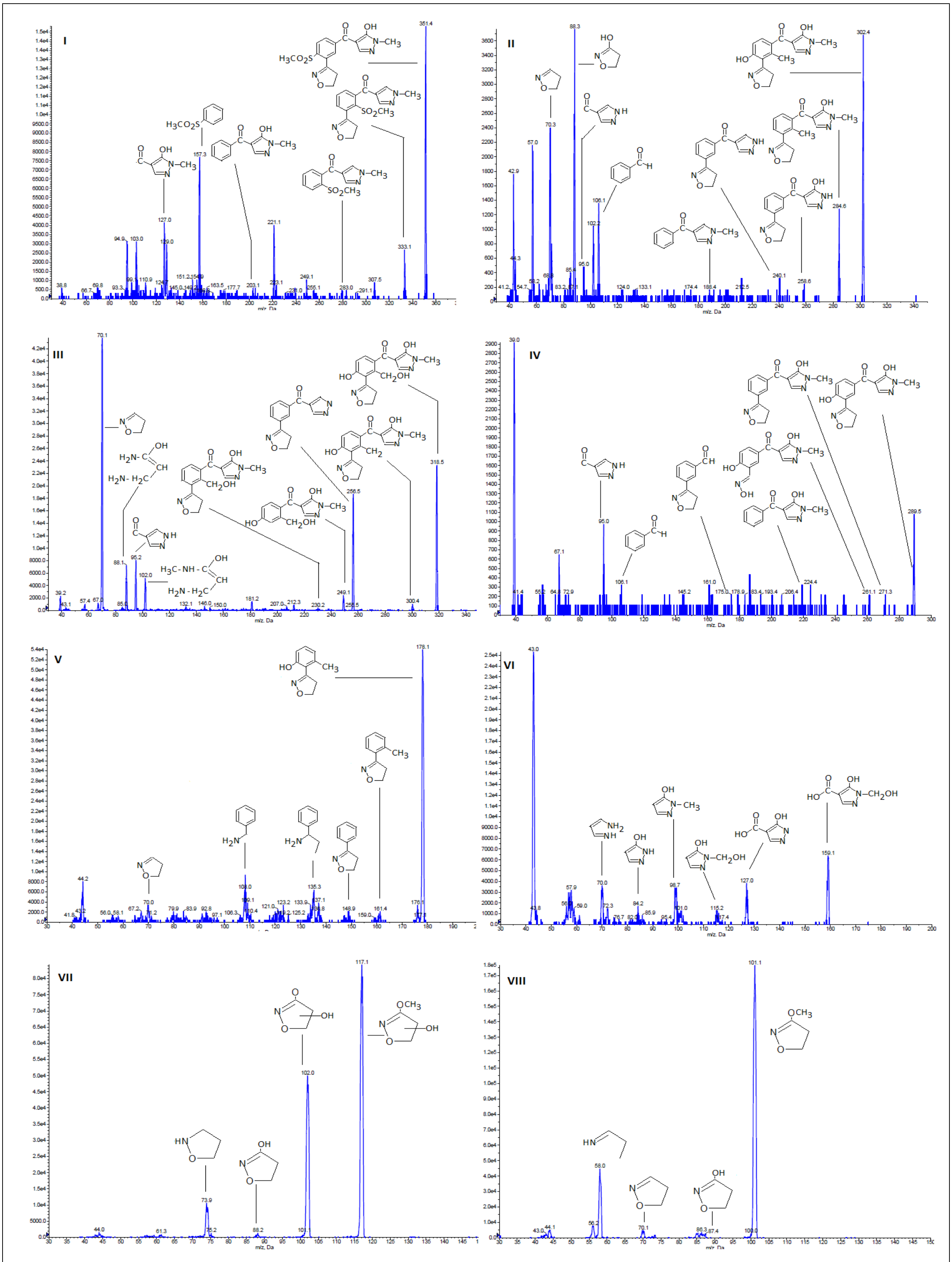

Figure 4. Proposed structures of degradation products and their fragmentation patterns on mass spectra recorded in (+) ESI mode

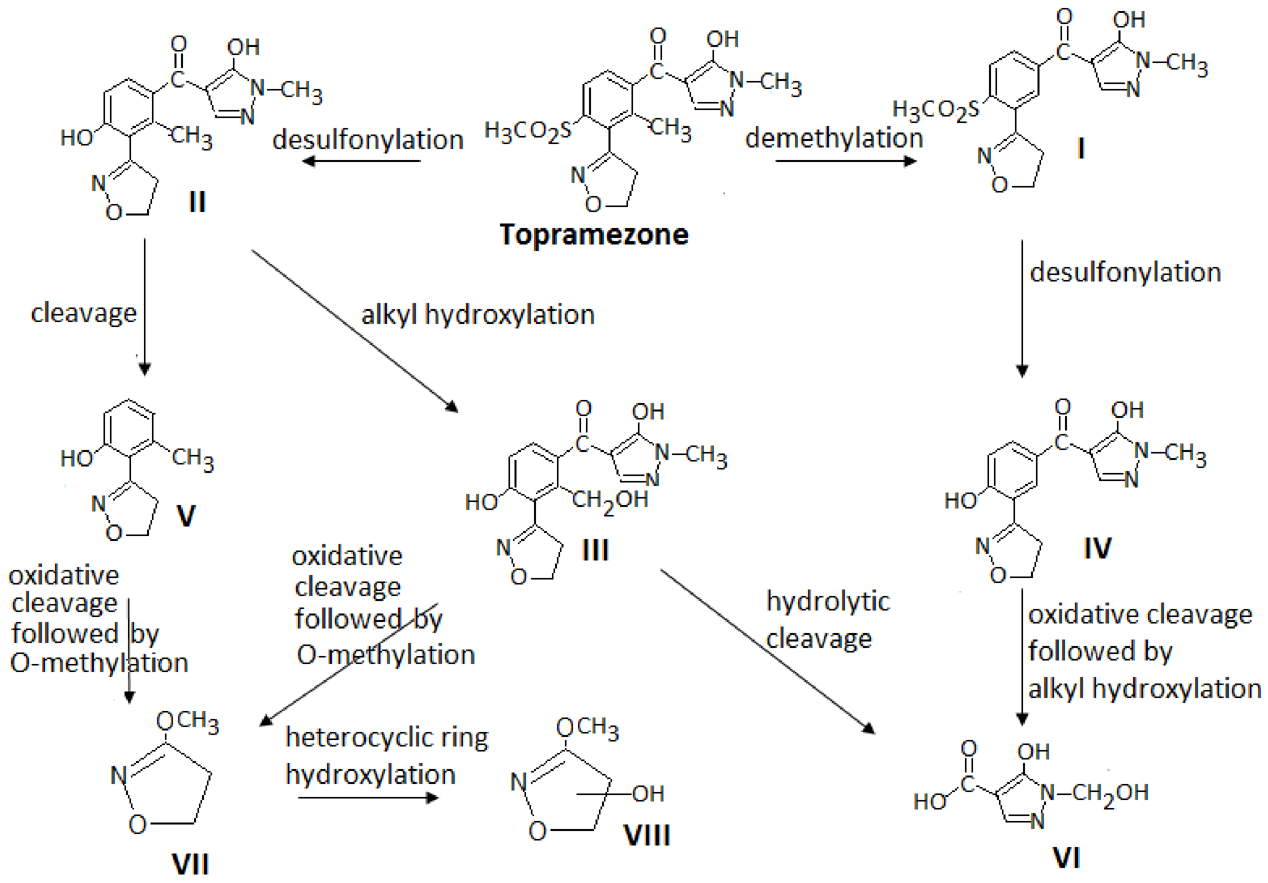

Figure 5. Proposed pathways for the degradation of topramezone by the *Trichoderma* isolate

Note: [I: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-mesylphenyl](5-hydroxy-1-methyl-pyrazol-4-yl)methanone, II: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-hydroxy-*o*-tolyl](5-hydroxy-1-methyl-pyrazol-4-yl)methanone, III: [3-(4,5-dihydro-1,2-oxazol-3-yl)-2-hydroxymethyl-4-hydroxyphenyl](5-hydroxy-1-methyl-pyrazol-4-yl)methanone, IV: [3-(4,5-dihydro-1,2-oxazol-3-yl)-4-hydroxyphenyl](5-hydroxy-1-methyl-pyrazol-4-yl)methanone, V: 2-(4,5-dihydro-1,2-isoxazol-3-yl)-4-hydroxytoluene, VI: 1-*hydroxymethyl*-5-hydroxy-4-pyrazolecarboxylic acid, VII: 1-methoxy-4-hydroxy-4,5-dihydroisoxazole, VIII: 1-methoxy-4,5-dihydro-isoxazole]

DISCUSSION

Our studies showed that incubation of the media containing topramezone, but without the fungal isolate, did not produce any significant amount of degradation of the herbicide. However, when incubated with the *Trichoderma* isolate both in the media and in soil, only about 15% of the applied topramezone persisted after 30 days of incubation.

A similar efficiency in degrading other pesticides by different strains of *Trichoderma* has also been reported. For example, *T. harzianum* 2023 rapidly degraded several organochlorine pesticides in culture media (Katayama and Matsumara, 1992). After 13 days of incubation, the amount of pesticides degraded were: DDT 20%, dieldrin 25%, endosulfan 40%, PCNB 50%, and PCP 88%. In another study, gamma ray irradiated *T. viride* and *T. harzianum* could also degraded 90% of applied Vydate®, a carbamate insecticide, in soil within 14 days of incubation (Helal and Abo-El-Seoud, 2014).

Based on our studies, the major routes of degradation of topramezone by the *Trichoderma* isolate appear to be demethylation; desulfonylation, followed by hydroxylation of the herbicides; alkyl hydroxylation; hydrolysis of the carbonyl group of ketone; methoxylation; and hetero ring hydroxylation. These are schematically presented in Figure 5.

A demethylation process converts the herbicide into the product I through several reaction steps, the first step of which is the hydroxylation of the methyl group attached to the aromatic ring. A similar reaction was observed during the degradation of toluene by *Cunninghamella elegans* Lendner (1907), a soil-borne fungus (Prenafeta-Boldú et al., 2001). The presence of the metabolite III containing the hydroxylated methyl group is strong evidence for this transformation of topramezone. The final step for this transformation involved a decarboxylation reaction, which had not been previously for *Trichoderma* species. However, a similar decarboxylation reaction of pyrrole-2-carboxylate, catalyzed by the pyrrole-2-carboxylate decarboxylase enzyme has been previously found in two bacteria, *Bacillus megaterium* PYR2910 and *Serratia* strains (Omura et al., 1998).

A desulfonylation process of sulfonyl derivative, which involves a multi-step oxidation reaction, catalyzed by oxygenase enzymes has not been much investigated during the fungal metabolism of such compounds (Linder, 2018). However, genetic and biochemical studies in the yeast *Saccharomyces cerevisiae* suggested that the metabolism of sulfonates proceeds through a sulfite intermediate, which is akin to the metabolism of sulfonates in bacteria (Uria-Nickelsen et al., 1993; Hogan et al., 1999). An enzymatic demethylation of sulfonylmethyl by a bacterium *Pseudomonas ananatis* (AF-264684) converted mesotrione to its demethylated metabolite, a sulfinic acid derivative (Pileggi et al., 2012). It has been reported that sulfinic acid gets readily oxidized by peroxidase to its corresponding sulfonic acid (Milev et al., 2015). The sulfonic acid moiety, attached to any aromatic group, is further oxidized by oxygenase forming a hydroxylated compound (Kalme et al., 2007). In the present study, topramezone underwent a similar desulfonylation process by the *Trichoderma* isolate, forming a hydroxylated product, the metabolite II. The product IV was also most likely formed from I, through a similar process.

Another major route of topramezone breakdown was the cleavage or hydrolysis of carbonyl group bearing two ring structures, a substituted phenyl and a substituted pyrazolyl group. The carbonyl group of topramezone was cleaved or hydrolyzed generating one carboxylic group attached to the pyrazolyl ring with the formation of a substituted pyrazolecarboxylic acid (metabolite VI), and the counter part of this hydrolysis, a substituted toluene (metabolite V). Similar hydrolysis of ketonic carbonyl group has been observed in the degradation of sulcotrione and mesotrione, two other triketonic herbicides, in soil and sediment (Durand et al., 2006; Barchanska et al., 2016).

The dissociation of dihydroisoxazole moiety from topramezone, or its immediate degradation products, metabolites I, II, III, IV and V, most likely occurred through the oxidative hydroxylation on the benzene-isoxazole linkage, followed by a methylation generating metabolite VII. The latter, on ring hydroxylation, produced the compound VIII. A similar, hydrogenase enzyme-based, ring hydroxylation has been reported as a key microbial process to open a heterocyclic ring for mineralization of an aromatic N-heterocyclic compound (Yoshida and Nagasowa, 2000). Although no terminal metabolite was isolated from the isoxazole, after the ring opening, the ring hydroxylation of isoxazole of the topramezone metabolite may have provided the foundation towards the mineralization of the herbicide.

Topramezone, being a highly persistent herbicide in soil, has the potential to remain in soil for long periods and contaminate both surface and ground water resources, through leaching. However, the application of *Trichoderma* sp. to fields that have received topramezone treatments, appears to have the capacity to expedite the degradation of the herbicide and thereby, minimize the risks of topramezone residues building up in soil and leaching out to contaminate water resources.

The application of *Trichoderma* formulations, as a bio-control agent, has already been standardized in managing plant diseases, such as downy mildew in grapevine cultivars (Banani et al., 2013); damping off in tomato (Montealegre et al., 2010); dry root rot in mung bean (Dubey et al., 2009); chickpea wilt in chickpea (Dubey et al., 2007); damping off in cucumber (Roberts et al., 2005); and wilt in pigeon pea (Prasad et al., 2002). Despite such applications in the existing literature, which we reviewed, there are not many reports available on the application of *Trichoderma* strains for the purpose of bioremediation of herbicides or other pesticides in contaminated soil.

In one recent study, conducted in Indonesia, Arfarita et al. (2016) reported a promising outcome, briefly reviewed below. Their studies demonstrated a high survival of a *Trichoderma viride* strain FRP3 in the fields, which had a history of more than 10-years of glyphosate application. In this study, the researchers used either a single or two applications of a conidial suspension (26 x 10^9 conidia g^{-1} media), in a volume of 5 L water, applied to each plot by a drip method, during a dry season (May-June 2013). While the control plots which received no additional conidial suspensions, had an indigenous microbial population of colony-forming-units CFU 0.66 x 10^6 g^{-1} soil, plots that received a single application of a conidial suspension had an increased population of microbes (CFU 8.83 x 10^6 g^{-1} soil). Plots that received two applications of the conidial suspension showed a correspondingly high microbial population with CFU of 15.97 x 10^6 g^{-1} soil. The number of colonies present in the experimental plots increased with time and correlated well with the amount of the conidia suspension of *Trichoderma viride* strain FRP3 that was introduced during the experimental period. The authors confirmed fast degradation of glyphosate using GC analysis of extracted soil samples. Within seven days after the *Trichoderma viride* strain FRP3 was applied to plots, the glyphosate content of the treated soil decreased significantly. With the single application of the conidial suspension, by the end of the experimental period of 28 days, glyphosate concentration decreased by 16 mg kg^{-1} (23.4%). In the plots that received two applications of the conidial suspension, glyphosate residues in soil decreased by 27.7 mg kg^{-1} (42.6%). When compared with the control plots, these results translated to 48% and 70% higher glyphosate degradation with a single or two applications, respectively, by the end of 28 days. The authors suggested that the fungal strain-*Trichoderma viride* strain FRP3, which had been widely used as a biological control agent in agriculture, could be used to degrade glyphosate quickly in soil contaminated with the herbicide.

The biodegradation ability of any *Trichoderma* strain would depend much on the quality of the formulation to be applied in a cropping field. Although *Trichoderma* mycelia and chlamydospores are known to have excellent biological activity, when applied to soil as suspensions, they do not survive well. Nor do they survive well during the formulation processing steps, such as drying. In contrast, the conidial suspensions are less susceptible to environmental conditions and are easily formulated (Amsellem et al., 1999; Whipps and Lumsden, 2001; Verma et al., 2005). Different, dry-flowable conidial formulations have been developed, which are quite effective in augmenting the concentrations of *Trichoderma* strains in the soil (Sriram et al., 2011; Muñoz-Celaya et al., 2012; Oancea et al., 2016; Locatellia et al., 2018).

Our studies indicate that further work is necessary to develop formulations of the *Trichoderma* strain that we isolated for field applications. Future research should focus on correctly identifying the *Trichoderma* isolate that we reported on, which can degrade topramezone fast. Following identification, research should focus on its mass culturing, to develop conidial suspensions that can be practically used in field situations.

Given that the half-life of topramezone in agricultural soil is long (about 120 days), the development and application of a beneficial fungus, such as the one we isolated, is suggested as promising to degrade topramezone from fields where the herbicide residues may have built up. Our results are suggestive of a degradation to about 50% of topramezone concentrations in soil by the *Trichoderma* isolate achievable in about 10 days. Such a development could assist in reducing the risks of topramezone residues building up in treated fields and mitigate the risks of the herbicide leaching into surface or groundwater resources.

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