PERSPECTIVE

Weed biology – A required foundation for effective weed management

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Abstract

Understanding of the biology of weeds (characteristics of seed production, seed dormancy, seedling emergence, plant growth, reproduction, and seed retention, as well as other physiological and morphological traits) is a prerequisite for the development of effective and sustainable weed management systems. Weeds are a persistent problem in agriculture, as they pose a direct threat to farmers' profitability. Farmers currently rely heavily on herbicides for weed control; however, the development of herbicide-resistance and mechanisms of phenotypic, as well as genetic plasticity, in weeds amount to significant challenges in weed management. These are in addition to the underlying issue of environmental pollution as an outcome of excessive herbicide use. The results of weed biology studies are essential to reducing or eliminating the abundance of weeds and the development of herbicide-resistant weeds. Integrated weed management strategies, IWM (e.g. narrow row spacing, competitive cultivars, optimum sowing time and planting density, and harvest weed seed control) for effective weed control can be linked to currently available information on weed biology. The integration of management techniques based on biological knowledge of individual weeds could provide for sustainable weed control and the mitigation of herbicide resistance under both current and projected conditions.

Keywords: crop husbandry, harvest weed-seed tactics, seed ecology, weed phenology, seed bank, weed seed reproduction

Introduction

Weed biology examines the establishment, growth, reproduction, and life cycles of weeds. Weed science uses primarily chemically and physiologically-based research to develop weed management systems. The underlying foundation of effective weed management is the practical research outcomes of the knowledge of multiple aspects of plants' seed germination, recruitment biology, and phenology to ensure sustainable management of individual weeds (Jordan et al., 2002; Westwood et al. 2018).

Knowledge of weed biology is essential for sustainable weed control (Harper, 1960). In-depth understanding of crop-weed interactions is dependent on knowledge of biology, genetics, environmental response, and the responses of both crops and weeds to management practices. Cropping system designs are based on the unique characteristics of weed populations and available weed management options. (Buhler, 2008). Current knowledge of weed biology should be incorporated with the study of ecological interactions, technological innovations, and decision-making algorithms to effectively contribute to the further development of integrated weed management strategies (Zimdahl, 2018).

Weeds are highly prolific seed producers, especially annual species, which can produce an abundant flush of seeds. A single plant of junglerice [*Echinochloa colona* (L.) Link], feather fingergrass (*Chloris virgata* Sw.), and African mustard (*Brassica tournefortii* Gouan) can produce >4,000 seeds per plant (Mahajan et al. 2020a, 2020b). Seed setting in a single mature weed plant presents the potential for the infestation of subsequent years of cropping.

Therefore, it is essential to break the cycle of seed bank replenishment. Generally, most weed seeds possess some level of dormancy; therefore, all seeds produced by a weed in a single year do not germinate the following year, instead, they survive in the soil according to their specific dormancy characteristics (Chauhan and Johnson, 2010; Mahajan et al., 2020b). While it has been observed that nearly all buried seeds of common groundsel *(Senecio vulgaris* L.*)* germinated or died over the course of two years of burial in soil (Figueroa, 2003), seeds of some other species [creeping buttercup (*Ranunculus repens* L.), common lambsquarters *(Chenopodium album* L.), and dock (*Rumex crispus* L.)] survived after 20 years because of high levels of dormancy in their seeds (Lewis, 1973).

Historically, the availability of information on weed biology greatly informed and improved weed management practices. The problem of perennial weeds, for example, has been reduced by cultivating weeds before the development of carbohydrate reserves in their root systems (Norris, 1992). Many weed management strategies have been developed based on the available biological information for the wild oat (*Avena fatua* L.) species. Wild oat management in Great Britain is now a classic example of the application of weed biology to improve control strategies (Fryer, 1981). This occurred because of the decision to collect more comprehensive information on the population dynamics of wild oat in the early 1970s and the ensuing interdisciplinary research into its biology and ecology. As a result, several aspects of control were modified, such as delaying post-harvest cultivation (to permit predation of seed) and the development of multiple herbicide control programs, rather than reliance on single herbicide applications. Such tactics resulted in a significant decline in the wild oat populations (Fryer, 1981).

In modern industrial agricultural systems, weed management relies heavily on the use of herbicides. The concept of weed biology has been largely neglected in the era of chemical weed control; however, with the development of herbicide-resistant weeds, it has become imperative to generate more information on the fitness penalty and increased seed dormancy in herbicide-resistant weeds (Navas, 1991). Knowledge of delayed germination, increased seed dormancy, and fitness penalty is especially important for the management of herbicide-resistant populations in weeds (Owen et al., 2015; Kumar and Jha 2017). Furthermore, the development of integrated weed management practices against herbicide-resistant weeds relies heavily on knowledge of weed biology for the generation of information on weed threshold levels, weed seed dynamics, and weed seed retention levels.

Knowledge of weed biology (e.g., phenology, competitive ability, seed production potential) is also required for assessing the impact of different weeds on revenue loss. It has been estimated that annual losses caused by weeds in Australian grain cropping systems are around AU$ 3.3 billion (Llewellyn et al., 2016). This figure is probably an underestimate, as it does not include the cost of soil erosion resulting from the cultivation required for weed control; nor does it account for the spread of weeds into nature reserves. It could be argued that costs incurred because of pollen allergens produced by weeds should also be accounted for.

While herbicide-based programs have helped in solving many issues of weed control, Weed Science has subsequently suffered from a lack of research into basic weed biology in the era of herbicides. With the increasing problem of herbicide-resistant weeds, researchers once again need an improved understanding of weeds to design effective integrated weed management systems that could delay the further evolution of herbicide-resistant weeds.

Concepts of Weed Biology

1. Identification of weeds and their biological traits

Accurate identification of weeds is essential to the implementation of effective weed management strategies. Without proper identification of the target species and the availability of information on the weed's taxonomy, management is reduced to a 'shot in the dark' approach (Chauhan et al., 2017). One example of improper identification is the case of *Oryza sativa* (weedy/red rice) in India where this weed species cannot be distinguished from volunteer rice plants. Information on biological traits of weeds, such as the morphology of plant canopies; root types, and their architecture; variation in leaf size, shape, and orientation could all help in assessing the competitive ability of weeds.

2. Physiology, biochemistry, and reproductive biology of weeds

Knowledge of the physiology of seed dormancy is essential for mitigating seed persistence in soil (Wesson and Wareing, 1969). The concept of night tillage was introduced based on varied germination behaviour of weed seeds under light and dark environments (Hartmann and Nezedal, 1990). For example, seeds of eclipta (*Eclipta prostrata* L.) did not germinate in the dark but germinated 76-93% in light (Chauhan and Jonson, 2008). Information on the photosynthetic rate of weeds in response to varying light interception levels has helped to form a better understanding of assessing growth and competition at a mechanistic level (Murphy et al., 2017). The mechanism of plant competition can be better understood through the early detection of weeds according to changes in light quality in the red: far-red ratio (Rajcan and Swanton, 2001).

Understanding of the mechanisms whereby weeds respond to moisture and nutrient stress could help in developing precise cultivation strategies to reduce competition. Physiological information on the flowering of weeds could aid in designing better weed management practices such as timely weed control and harvest weed seed control tactics (Norris, 1992; Chauhan et al., 2017). This remains a little-explored aspect of weed physiology that presents great potential for new approaches to managing weeds.

Much work has been done on the effect of weed density and the duration of weed competition on crop yield losses; however, little information has been generated in understanding the mechanism through which crop and weed plants interact with each other and provide signals to each other (Tilman, 1987; Campbell et al., 1991; Grime et al., 1991; Westwood et al., 2018). There is a need to generate information on the mechanism of competition, rather than just quantifying the magnitude of losses. Specifically, what physiological and heritable changes may occur in crop plants in response to competition created by neighbouring weed seedlings and how this knowledge could be useful in assessing crop yield losses.

3. Dynamics of weed seed banks

Knowledge of weed seed banks is critical to the implementation of effective weed management (Chauhan and Johnson, 2010). Much of the existing weed seed longevity data are overestimations due to varying protocols amongst researchers, often excluding predation (Roberts, 1981; Cavers, 1989; Chauhan and Johnson, 2010). Most weed seed longevity studies have been conducted on bare soil, indicating the possibility of highly variable outcomes under conservation tillage systems.

There is the possibility that crop residues in the field affect weed seed germination by releasing allelochemicals. It has been observed that soil amended with residues of sunflower (*Helianthus annuus* L.) and sorghum [Sorghum bicolor (L.) Moench.] resulted in reduced biomass of *E. colona* due to allelochemicals released by either crop (Khaliq et al., 2011). Therefore, there is a need for weed seed longevity studies in conservation agriculture systems that incorporate residue retention in their fields. In-depth knowledge of seed banks could provide an important contribution to weed management.

It is also essential to understand the mechanism of seed decay rather than to limit the outcome of these studies to decayed seed numbers. The regulatory mechanism of decayed seeds could help in designing optimum management strategies. Information is limited regarding the mechanism of spread and invasion of weeds such as mimosa (*Mimosa invisa* Mart.); kochia (Kochia *scoparia* L. Schrad;) gorse (*Ulex europaeus* L.); common milkweed (*Asclepias syriaca* L.) in different geographical regions.

Information on the phenology of weeds under different environments could provide valuable contributions to weed management practices, particularly in the wake of climate change. For example, early flowering in weeds in response to temperature increases may result in the shattering of weed seeds before crop maturity, and thereby replenish weed populations. Information on the development of an economic threshold level for weeds is particularly crucial in optimizing weed control strategies. The magnitude of seed rain produced by weeds is not well known. Information on the seed retention behaviour of weeds could help in optimizing harvest weed seed control strategies (Mahajan et al., 2020b; Walsh et al., 2013). Most farmers in Australia and the USA now attempt to decrease weed seed production in their fields to minimize future problems. They are successfully using harvest weed seed control practices for certain weeds because of greater biological knowledge.

4. Evolutionary changes in weeds

The genetics of herbicide-resistant biotypes and their ability to hybridize is a new principle research area for weed scientists. Knowledge of the biology and ecology of weeds, as well as factors that affect biological traits, is essential to the development of better-integrated weed management strategies (Chauhan et al., 2017). However, the significance of this research has been under-estimated as its effects are indirect. Weed biology studies do not create new management products (e.g., herbicides). However, they do provide a concept for weed management that can be successfully used in making informed decisions in the selection of control tactics for researchers, growers, and industry. Identification of weeds resulting from a population shift or having adapted traits for different mechanisms of spread could prove valuable in the near future. This knowledge-base provides the opportunity for a screening program for the prediction of future weed problems. For example, a screening program to identify evolutionary forces responsible for target and nontarget site herbicide resistance.

5. Weed biology and effective weed management

Advanced knowledge of weed biology could aid in improved planning and projection for new molecular sites of herbicide action and the development of herbicides that block specific metabolic pathways. It could also aid in determining the best time to apply herbicides due to the accurate determination of a weed's sensitive physiological stages. Knowledge of weed biology could aid in developing effective weed control programs based on the integrated use of crop production methods, tillage practices, and herbicide selection. It may also assist in developing new techniques, such as robotic weed control.

Weed prescription maps can be prepared by utilizing weed phenology information to forecast weed losses. Modelling the hydrothermal, population-dynamics, and crop–weed interaction of various weeds, can be achieved thanks to weed biological information in order to assess the impact of weeds in advance. Crop-weed competition studies help in strengthening an integrated weed management program by suggesting agronomic techniques (sowing time, row spacing, planting density) that could make the crop more competitive. No doubt, an integrated weed management system is a technically sound program, however, for proper implementation of these techniques, the social, environmental, and economic advantages and disadvantages associated with any agronomic practices need to be ascertained. If growers are not convinced by the economic viability of an integrated weed management system, then implementation is inevitably hampered. In this regard, information on weed biology could help in developing viable integrated weed management practices.

Conclusions

Weed will always be present in agricultural fields and elsewhere, so long as disturbances occur. Knowledge of weed biology could provide a practical solution to improve weed management and to lessen dependence upon herbicides to manage the negative impacts of weeds. With more biological information on weeds, farmers and weed managers could effectively control weeds and save money. Weed scientists should seek to integrate their research with ecologists and biologists to augment the significance of results for practical and successful weed management.

Specifically, knowledge of weed dormancy and germination behaviour could be used to predict field emergence patterns. Information on their phenological and reproductive behaviour could improve timely weed management. Growing degree-day models based on the phenological stages of weeds could help managers make decisions for cultural practices and timely herbicide control. Weed seed retention knowledge could aid in the development of harvest weed seed control practices. Without the advancement and implementation of weed biological information, any of these advances in weed management remain limited due to serious gaps in understanding of those species directly impacting cropping and ecological systems.

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