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Role of competition in managing weeds: An introduction to the special issue

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A B S T R A C T

Weeds represent a significant challenge to successful crop production. Highly effective and sustainable weed control is required in order to meet global food demand. In this context, excessive use of herbicides has resulted in serious environmental and ecological issues. There are several weed control options which neither harm the environment nor require a significant increase in cost of production. Improving crop competition is particularly important and attractive among such options, which can be achieved by using crop cultivars possessing a competitive advantage over weeds, and manipulating the seed rate and direction of crop rows. Crop cultivars possessing traits such as fast germination, quick growth, high biomass, and large leaf area have a competitive advantage over weeds. Sowing such cultivars has been shown to suppress weeds in various crops. The use of high seed rates and narrow row spacing, if properly manipulated, can cause a significant decrease in weed proliferation in the crops. These techniques (cultivar, seed rate, row spacing, and row direction) are under-exploited as weed control methods, and offer considerable potential for achieving environmentally benign weed management. This special issue on "Eco-friendly Weed Management" will address the role of crop competition in managing weeds in different crops as well as in different countries.

1. Introduction

The world's population is increasing by over 74 million per year, which will accumulate to approximately 2.4 billion additional people by 2050. Global demand for crop calories is expected to double between 2005 and 2050 (Tilman et al., 2011). It is projected that, by 2050, the world's annual demand for the three major cereal crops, rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.), will be around 3.3 billion tonnes (FAO, 2016). Globally, wheat is the most important source of calories for humans, contributing approximately 20% of daily dietary calories followed by rice (19%) and maize (5%) (Curtis, 2002). Wheat is also the most important source of protein, and contributes about 21% to the daily dietary protein intake of humans. Soybean (*Glycine max* L.) is another key source of protein, and together with canola (rape) (*Brassica napus* L.), occupies a place of prominence as a source of edible oil. Rotation of these crops (soybean and canola) plays an important role in diversification of cereal-dominated cropping systems in Australia, Canada, and several European countries, with beneficial consequences for management of weeds, disease, insect pests, and nutrition.

Several biotic and abiotic factors influence crop productivity. Weeds deplete limited resources essential for crop growth, and persistent weed interference not only causes heavy yield losses, but increases production costs and reduces the quality of produce. Crop-weed competition is influenced by three major factors, viz. time of emergence of weeds, weed density, and type of weed species. Weeds that emerge before (or simultaneously) with the crop will be more competitive than weeds that emerge after crop establishment. At a similar density, different species of weeds may vary in their ability to compete with crop plants, due to dissimilarities in their growth habit, and through allelopathic effects on germination and growth of crop seedlings. In dry areas, perennial weeds like *Cirsium arvense* L. and *Convolvulus arvensis* L. are more competitive than annual weeds, owing to their deep roots, early vigour, and dense shoot growth.

The intensity and duration of crop-weed competition determines the magnitude of crop yield losses (Swanton et al., 2015).

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In the absence of effective weed management, the potential crop yield losses due to weeds often exceeds that of animals (arthropods, nematodes, rodents, birds, slugs, and snails), pathogens (fungi and bacteria), and viruses (Oerke, 2006). Significant yield losses due to weeds have been reported in rice (10–100%), wheat (10–60%), and maize (25–93%) (Lal and Saini, 1985; Sharma and Thakur, 1998; Pandey et al., 1999; Rao et al., 2014; Jabran and Chauhan, 2015; Yaduraju et al., 2015). Therefore, effective weed management is a key element in agricultural production, essential for realizing the increased production targets necessary to meet the food demands of the burgeoning global population. Globally, weeds are responsible for decreasing the production of the world's eight most important food and cash crops by 13.2% (Oerke, 2006). In economic terms, weeds not only caused annual crop loss amounting to more than U.S. $100 billion worldwide, and use of herbicides for weed control incurred additional expenditure of about U.S. $25 billion (Agrow, 2003).

A special issue on "Eco-friendly Weed management" is planned. In this special issue, an attempt has been made to justify that any weed management approach, even non-chemical, that is continuously repeated provides heavy selection pressure for weed adaptation and resistance to that practice. Therefore, in eco-friendly weed management approaches, using a diversity of approaches is more important than striving to exclude any single method (e.g., herbicide). Eco-friendly weed management priorities that have been highlighted in this special issue may increase the chance of funding levels from various agencies towards this thrust area. Through this special issue, the improved education of growers would lead to the long-term benefits of eco-friendly weed management approaches, and may facilitate crucial changes in research direction.

There will be wide adoption of some of these eco-friendly weed management approaches but not of others in the wake of herbicide resistance, depending on their cost-effectiveness. In considering the cost-effectiveness of these approaches, complementary benefits to aspects other than weed control will become increasingly important. In herbicide-resistant weed fields, sometimes, it becomes very difficult to determine the impacts of each eco-friendly approach in order to assess their individual worthiness for managing herbicide resistance. Some treatments have impacts that are relatively difficult to observe even if implemented in isolation. For example, the smothering effect of crop with increasing seeding rates affects the seed production of weeds and it is rather difficult to observe quantitatively in the field without tedious collection and counting of weed seeds in both check and treatment plots.

The effectiveness of some eco-friendly approaches are very sensitive to weather conditions or the quality of implementation, and therefore, trials give highly variable results from time to time. Even if any approach is beneficial in the long run, it may not appear so in a short-term trial, or it may take a long time before its value can be determined with adequate confidence. All of these factors would tend to discourage the rapid adoption of eco-friendly approaches for weed management. On the other hand, the nature of herbicide resistance is that, once it has developed, farmers have no choice but to alter their weed management systems. The problem for farmers then becomes, which of the many possible alternative systems should best be adopted?

Several of research papers discuss the role of genotypes, seed rate, row spacing and row direction in suppressing weeds, however, a review article is rarely available to discuss these practices in relation to improving crop competition for weed management. This is the 'introductory review' to the special issue of Crop Protection entitled 'Eco-friendly weed management'. In this review, we have explained the problems being faced under the current weed management scenarios, and use of crop competition as a promising weed control strategy. Additionally we have discussed the utility of strategies such as seed rate, row spacing, crop cultivar and row-direction to improve the competitive ability of crops and achieve an effective weed control.

2. Weed management practices

Weed control measures account for significant crop production costs (Oerke, 2006). Ever since the first use of herbicides for weed management, their application has become widespread in the developed world (Borlaug, 2002). Herbicide-based weed management has become the dominant tool for weed control in modern agriculture due to efficacy on most weeds, cost effectiveness, ease of application, and ability to reduce labour requirements (Chauhan et al., 2012). Herbicides are very effective in controlling certain grassy weeds such as *Echinochloa* spp. in rice (Mahajan and Chauhan, 2013), and *Phalaris minor* Retz., *Avena fatua* L., and *A. ludoviciana* Dur. in wheat, which may otherwise escape removal through manual or mechanical means, due to their morphological similarity to the crop (Rao and Moody, 1988).

The success of conservation agriculture, which has environmental and economic advantages over conventional tillage-based agriculture, relies heavily on herbicides, especially glyphosate. However, long-term use of herbicides with the same mode of action, coupled with faulty spray techniques and incorrect application rates, have resulted in the evolution of herbicide resistant (HR) weeds worldwide by imposing selection pressure (Malik and Singh, 1993). Other factors that influence the rate of appearance of resistance are the initial resistance gene frequency, residual activity of herbicide, the genetic basis of resistance, how prolific the weed is at producing seed, seed longevity in the soil and the fitness of resistant traits (Beckie, 2006; Powles and Yu, 2010; Egan et al., 2011; Heap, 2016). There is a continuous increase in the number of HR weed populations (Norsworthy et al., 2012), and herbicides once considered a boon for agriculture have now become useless in many cropping situations. Since the first case of HR in the early 80s, the problem has increased manyfold. The International Survey of Herbicide Resistant Weeds (weedscience.org) has documented 467 unique cases (species × site of action) of HR weeds across the globe (Heap, 2016). A total of 249 HR weed species (144 dicots and 105 monocots) have been documented in 86 crops and 66 countries. The increasing pace of herbicide resistance in weeds poses a serious threat to the sustainability of crop production worldwide. Owing to the evolution of resistance in *P. minor* against the herbicide isoproturon, this weed has become the single plant species limiting wheat productivity in India (Malik and Singh, 1993; Chhokar and Malik, 2002; Chhokar and Sharma, 2008). The cost of managing HR weeds is escalating, and no new herbicide site-of-action has been discovered during the last two decades (Duke, 2012). Added to this, there is increasing concern over non-target impacts of herbicides on humans and organisms (Boily et al., 2013; Helmer et al., 2014; Santadino et al., 2014; Mensah et al., 2015; Beecham and Seneff, 2016; Portier et al., 2016).

Excessive use of herbicides has resulted in serious environmental and ecological issues. Most herbicides are specifically plant poisons, and are not very toxic to animals. There are exceptions, however, as is the case with the herbicide paraquat. By inducing large changes in vegetation, herbicides can evolve the problem of herbicide-resistant weeds, noxious weeds such as weedy rice (Chauhan et al., 2012), and indirectly affect populations of birds, mammals, insects, and other animals through changes in the nature of their habitat (Waite et al., 2002; Brown, 2004; Orhii, 2010).

The situation demands development and implementation of integrated weed management (IWM) strategies to curb the resistance problem in cropping systems (Norsworthy et al., 2012; Vencill