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Review

Allelopathy for weed control in agricultural systems

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ABSTRACT

Weeds are a hidden foe for crop plants, interfering with their functions and suppressing their growth and development. Yield losses of ~34% are caused by weeds among the major crops, which are grown worldwide. These yield losses are higher than the losses caused by other pests in the crops. Sustainable weed management is needed in the wake of a huge decline in crop outputs due to weed pressure. A diversity in weed management tools ensures sustainable weed control and reduces chances of herbicide resistance development in weeds. Allelopathy as a tool, can be importantly used to combat the challenges of environmental pollution and herbicide resistance development. This review article provides a recent update regarding the practical application of allelopathy for weed control in agricultural systems. Several studies elaborate on the significance of allelopathy for weed management. Rye, sorghum, rice, sunflower, rape seed, and wheat have been documented as important allelopathic crops. These crops express their allelopathic potential by releasing allelochemicals which not only suppress weeds, but also promote underground microbial activities. Crop cultivars with allelopathic potentials can be grown to suppress weeds under field conditions. Further, several types of allelopathic plants can be intercropped with other crops to smother weeds. The use of allelopathic cover crops and mulches can reduce weed pressure in field crops. Rotating a routine crop with an allelopathic crop for one season is another method of allelopathic weed control. Importantly, plant breeding can be explored to improve the allelopathic potential of crop cultivars. In conclusion, allelopathy can be utilized for suppressing weeds in field crops. Allelopathy has a pertinent significance for ecological, sustainable, and integrated weed management systems.

1. Introduction

Weeds constantly compete with crop plants to cause a considerable loss in their productivity. Hence, weeds have been documented as serious plant pests since the ancient times (Zimdahl, 2013). Weeds have always played a role throughout the domestication of crop plants which necessitated practicing weed control measures (Oerke et al., 1999; Zimdahl, 2013). Pulling by hand, cutting, and physically smothering weeds were among the ancient methods of weed control (Oerke et al., 1999; Young et al., 2014). Over time, hand tools were developed to till soils in order to control weeds. During recent times, herbicides and other modern means of weed control have been used. However, since the beginning of agriculture, hand weeding, mechanical weeding, and herbicide applications have been the most relied upon weed control methods (Griepentrog and Dedousis, 2010; Bergin, 2011; Rueda-Ayala et al., 2011; Chauvel et al., 2012). These weed control methods have served to keep weed infestations low and improve the crop productivity throughout the world.

Despite the significant contribution of these weed control methods in improving crop productivity, certain challenges are also associated with them. Decreasing availability and increasing cost of labour, and inconsistent weed control are among the major challenges in hand weeding (Carballido et al., 2013; Gianessi, 2013). Similarly, mechanical weed control requires extra soil turn-over, which can disturb soil structure and deplete soil fertility (Smith et al., 2011). Mechanical weed control is not always effective and can be expensive and lack durability (Bond and Grundy, 2001). Likewise, herbicide-resistant weeds, health effects, and environmental concerns are the major constraints for repeatedly using herbicides for weed control (Annett et al., 2014; Hoppin, 2014;

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Powles, 2008; Starling et al., 2014). The challenges associated with conventional weed control methods (e.g., hand weeding, mechanical control, herbicides, etc.) make it imperative to develop diversity in the current weed control methods. A variety of options would be available for site specific weed control if diverse weed management methods are developed. The cost and ecological concerns can be firmly addressed by using diversified weed management options. Suppressing weeds by harnessing the allelopathic phenomenon is included among the important innovative weed control methods (Jabran and Farooq, 2013; Zeng, 2014). Plant hormones and defence mechanisms are manipulated to control weeds in different agro-ecosystems (Pickett et al., 2014).

This review article discusses the practical application of allelopathy for weed control in agricultural systems. Further, we have focused on the implications of weeds in crop production, challenges in weed management, potential allelopathic crops, and the use of allelopathy for managing weeds. Strategies, such as the use of allelopathic cultivars, intercropping with allelopathic weed suppressive plants, the use of allelopathic cover crops and residues, and rotational sowing of allelopathic crops, have been discussed for practical weed control in field crops.

2. Weeds and crop production

Weeds coincide spatially with crop plants. They deprive the crop plants from limited available nutrients, space, light, and moisture. Hence, the physiological activities and growth of crops are negatively affected in the presence of weeds (Rajcan and Swanton, 2001). Ultimately, poor crop productivity is the result, due to weed-crop competition.

Among all types of crop pests, weeds are known to cause the greatest yield reductions in the crops (Oerke et al., 1999). On an average, weeds can lower crop productivity by 34% (Oerke, 2006). The potential yield reductions by weeds in some important crops are: wheat 23%, soybeans 37%, rice 37%, maize 40%, cotton 36%, and potatoes 30% (Oerke, 2006).

Weeds have indirect effects on crop plants. Crop development is affected by allelopathy from certain weed species. Allelochemicals from allelopathic weeds can disturb the root and shoot growth of emerging crop seedlings, as well as cause several other damages. In a recent study, Dmitrović et al. (2014) reported that allelochemicals excreted from *Chenopodium murale* L. root hairs were responsible for the cell cycle disturbance and oxidative damage in wheat and *Arabidopsis thaliana* seedlings. Similarly, allelopathic water extracts from weed species, including *Malva parviflora* L. and *C. murale*, were shown to inhibit the growth and photosynthetic activity in barley (Al-Johani et al., 2012). The invasive weed *Flaveria bidentis* (L.) Kuntze was found to excrete allelopathic phenolic compounds (Zhang et al., 2012). Residues from this weed inhibited the growth and biomass of cotton seedlings. Weeds can also impact crop yield by serving as alternate hosts for many insect pests and plant diseases. Weeds can interfere with harvest of the crop in addition to elevating the cost of production from the cost associated with their control.

3. Challenges in weed management

With world population increasing and available resources decreasing, weed management is an even more important as well as a challenging job. Accurate weed control is compulsory for food security throughout the world. Currently, most reliable weed control methods include herbicide application, mechanical weeding, and hand weeding. However, the sustainability of long term chemical weed control is facing certain challenges. Most important among these challenges is the evolution of herbicide resistance in weeds. The other problems faced in weed management with herbicides are the negative impacts of herbicides on environmental, human and animal health. Most importantly, herbicides, with few exceptions, cannot be applied in fields in which crops are being grown organically. Under certain cases, small-scale farmers cannot afford the expense of herbicides. Mechanical weed control on the other hand, needs to be performed several times to achieve effective weed control. Mechanical weed control poses an economic and soil health expense, due to losses in soil structure. Hand hoeing is a weed control method largely followed throughout the world. This method though, requires an enormous amount of labour, and hence is difficult to practice on a large scale.

Several of the above problems with current weed management practices can be allayed by creating diversity in weed control practices. A dependence on more than one weed control method has proved to be effective in reducing the chances of herbicide resistance development in weeds. Further, using diverse weed management practices on certain fields can ensure sustainable and effective weed control. Thus, manipulating the allelopathic phenomenon can help to improve weed control in crops by harnessing the synergism to improve the efficacy of other weed control methods.

4. Potential allelopathic crops

Several plants express the allelopathic phenomenon through exudation of allelochemicals. For example, rye is among the most important allelopathic crops. Although benzoxazinones [2,4-dihydroxy-1,4(2H)-benzoxazin-3-one (DIBOA) and 2(3H)-benzoxazolinone (BOA)] are the most important allelochemicals responsible for the allelopathic potential of rye, several of other important allelochemicals are also present in rye. Recently, Schulz et al. (2013) reviewed the allelopathic potential of rye and listed 16 allelochemicals present in this plant. These allelochemicals included β-phenyllactic acid, protocatechuic acid, DIBOA (glucoside), vanillic acid, apigenin-glycosides, syringic acid, luteolinglucuronides, *p*-hydroxybenzoic acid, *p*-coumaric acid, benzoxazolinones BOA, cyanidin glycosides, β-hydroxybutric acid, isovitexinglucosides, DIMBOA (glucoside), gallic acid, and ferulic acid/conjugates. Further, a number of studies reported the allelopathic inhibition of other crops and weeds by rye (Bertholdsson et al., 2012; Didon et al., 2014; Macias et al., 2014). Although rye can be manipulated to suppress weeds in a cropping system as a rotational crop, cover crop, or mulch, using it as a cover crop is the most common method for weed control (Norsworthy et al., 2011; Tabaglio et al., 2013).

Sorghum is another important allelopathic crop. Extensive literature explains the allelopathic potential of sorghum and its implications in different cropping systems. The allelopathic activity of sorghum varies across cultivars, environmental conditions, and plant growth stages. Sorghum expresses its allelopathic activity through the production of several allelochemicals. Most important among these allelochemicals are hydrophobic *p*-benzoquinone (sorgoleone), phenolics, and acyanogenic glycoside (dhurrin) (Weston et al., 2013). Sorgoleone is the most potent allelochemical of sorghum exuded by its roots. Root hair cells are responsible for the production of sogoleone in sorghum plants (Weston et al., 2012). The allelopathic activity of sorghum can be manipulated for weed control by planting allelopathic cultivars, applying sorghum residues as mulch, using sorghum as cover crop and intercrop, or including sorghum cultivars in a crop rotation.

The Brassicaceae family has a strong allelopathic potential against other crop and weed plants (Haramoto and Gallandt, 2004). Brassicas produce the allelopathic compound glucosinolate throughout their plant parts (Fahey et al., 2001). However, the concentration of this allelochemical varies in different parts of the