Role of Allelopathy in Weed Management: A Review

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ABSTRACT

Allelopathy is the releasing of allelopathic compounds by one plant species that inhibit the growth and development of neighbouring plants of another species. Weeds, besides removing moisture and nutrients, harbour insects and diseases. Manual weed management practices are laborious and expensive. In spite of herbicides being effective in increasing yield, indiscriminate use of herbicides has resulted in serious ecological implications such as development of herbicide resistance weeds and shift in weed population. Recently, research attention has been focused to find out alternative strategies for chemical weed control in several crops. Reduction in herbicide use is one of major goals of modern agriculture and there is much emphasis in search for alternative weed management strategies that are cheap, safe and sustainable. Allelopathy is considered as an effective, economical and environment friendly weed management approach. The release of allelopathic compounds from leaves, flowers, seeds, stems and roots of living and decomposing plant materials can influence weed density and growth. Keeping this in view, the literatures on allelopathic effect of crops and trees on weeds are reviewed in this paper.

Key words: Allelopathy, Herbicides, Herbicide resistance, Weeds, Weed management.

The term allelopathy was coined by a plant physiologist Molisch (1937), consisting of two Greek words, allelon meaning ‘mutual’ and pathos meaning ‘to suffer’, harmful effects on each other (Chon and Nelson, 2012). Allelopathy is a natural ecological phenomenon in which different organisms affect the functioning of other organisms in their vicinity, negatively or positively (Rice, 1984). Allelopathy is the releasing of allelopathic compounds by one plant species that inhibit the growth and development of neighbouring plants of another species (Weston and Duke, 2003). The release of allelopathic compounds from leaves, flowers, seeds, stems and roots of living and decomposing plant materials can influence weed density and growth (Tesi and Ferrero, 2010). The allelopathic crops can be used as intercrops, mulches or water extracts (Fujii, 2003). Sorghum and sunflower are considered highly allelopathic crops, producing many allelopathic compounds like sorgoleone, glycosides, alkaloids, flavonoids, phenolics and terpenoids (Iqbal and Cheema, 2008).

Chemicals thus released, the allelochemicals, are mostly secondary metabolites, which are produced as by products during different physiological processes in plants (Faroq et al., 2011a and Bhadoria, 2011). Important secondary metabolites identified as allelochemicals are phenolics, alkaloids, flavonoids, terpenoids, momilactone, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates, carbohydrates and amino acids (Kruse et al., 2000; Jabran and Farooq, 2012). Action of these compounds is concentration dependent (Einhellig, 1986) as they inhibit the plant growth at high concentrations and promote that at low concentrations (Narwal, 1994). These allelochemicals may thus be used as natural pesticides at high concentration (Faroq et al., 2009b). Inhibitory role of allelochemicals is well explored and has been directly and indirectly used for weed management. A lot of research work has been done to explore the inhibitory potential of different allelopathic crops and trees for weed management (Faroq et al., 2011b).

It is pragmatic substitute of synthetic herbicides as allelochemicals do not have residual or toxic effects (Bhadoria, 2011). This inhibitory feature is attributed to the blockage or cessation of important physiological and metabolic processes of plant. On the other hand, allelochemicals promote growth and impart resistance against several abiotic stresses (Faroq et al., 2009 a) at low concentrations. Only a few studies have been carried out to investigate the growth promotion by the allelochemicals. Application of water extracts of allelopathic compounds at lower concentrations stimulates germination and growth of different crops (Cheema et al., 2012). Application of allelochemicals at low concentrations to crops can be a cost-effective and efficient way to promote growth and to enhance crop productivity (Oudhia et al., 1988).
Releasing allelopathic compounds into the environment

Allelochemicals can be found in different concentrations in several parts of plants viz., leaves, stems, roots, rhizomes, seeds, flowers and even pollen (Bertin et al., 2003) and their pathway of release into the environment varies among species. The following are known pathways: (1) exudation and deposition on the leaf surface with subsequent washing off by rainfall; (2) exudation of volatile compounds from living green parts of the plant; (3) decay of plant residues (e.g., litterfall or dead roots) and (4) root exudation (Chon et al., 2006). Different types of abiotic and biotic stress can alter the production and release of allelochemicals during the vital cycle of plants. Drought, irradiation, temperature, nutrient limitation, competitors, disease and damage from insects have been pointed out as factors that can cause an increased release of allelochemicals from allelopathic plants (Cseke and Kaufman, 2006).

Allelopathy and weed management

Weeds are the most stubborn competitors of crops causing substantial reduction in yield by sharing light, air, water, nutrients and space. Allelopathic water extracts have been successfully used for organic weed management. Allelochemicals are diverse in nature and structure and thus lack common mode of action. When applied at high concentrations, these allelochemicals interfere with the cell division, hormone biosynthesis and mineral uptake and transport (Rizvi et al., 1992), membrane permeability (Harper and Balke, 1981), stomatal oscillations, photosynthesis (Einheilig and Rasmussen, 1979), respiration and protein metabolism (Kruse et al., 2000) and plant water relations (Rice, 1984), which may cause substantial growth reduction. This phytotoxic activity of allelochemicals is responsible for growth suppression of weeds. Flavonoids and phenolics suppressed the germination and growth of several plants (Sadeghi et al., 2010). Allelochemicals reduce water and nutrients uptake by roots and inhibit photosynthesis, respiration, protein synthesis, cell division and thickness of seminal roots as well as cause slow maturation and delay or failure of reproduction (Jafariehyazdi and Javidfar, 2011).

Crops with allelopathic potential for weed control sorghum

Allelopathic crops offer strong potential for the development of cultivars that are highly weed-suppressive. Allelopathic plants such as sorghum (Weston, 1996) and sunflower (Anjum and Bajwa, 2008) are inhibitory to weeds. Sorghum is one of the most widely used crop water extracts as natural herbicide. Sorghum contains several phytotoxins, namely gallic acid, protocateuic acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, p-coumaric acid, benzoic acid, ferulic acid, m-coumaric acid, caffeic acids, p-hydroxybenzalde hyde and sorgoleone (Weston, 1996). Netzley and Butler (1986) isolated sorgoleone [2- hydroxy- 5- methoxy- 3- [(8Z, IIZ)- 8', 11', 14'- pentadecatriene]- p- benzoquinon] from hydrophobic root exudates of sorghum. Sorgoleone, the major p-benzoquinone and three other structurally related minor p-benzoquinones together constitute 90 per cent or more of the root exudates (Netzly et al., 1988). Sorgoleone is primarily an inhibitor of plant growth through inhibition of photosynthesis and respiration (Duke et al., 2007).

Mulches of sorghum or Sudan grass (Putnam and DeFrank, 1979) applied to apple orchards in early spring reduced weed biomass by 90 and 85 per cent, respectively. Sorgaab (Sorghum water extract) sprays and sorghum mulch treatments suppressed the total weed density by 13-54 per cent and 23-62 per cent, respectively. Forney et al. (1985) indicated sorghum as annual cover crop because of its rapid growth and ability to suppress weeds. According to Cheema (1988), nine water soluble allelochemicals of sorghum (Sorghum bicolor L.) are phytotoxic to the growth of certain weeds like Phalaris minor Retz., Chenopodium album L., Rumex dentatus L. and Convolvulus arvensis L. He also found that incorporation of sorghum roots into soil suppressed the weed biomass by 25-50 per cent and increased wheat yields by 7-8 per cent. Sorghum allelochemicals are species specific and concentration dependent in their effect (Cheema and Ahmad, 1992).

Two foliar sprays of sorgaab (Sorghum water extract) inhibited weed dry weight by 15-53 per cent and improved wheat yield by 14 per cent. The allelopathic potential of water extract of sorghum and sunflower against weeds in the field of wheat crop revealed that spray of 100 per cent water extracts of sorghum and sunflower at 30 DAS significantly reduced the total weed density up to 48 and 32 per cent and weed dry weight up to 51 per cent (Cheema et al., 1997). Allelopathic properties of sorghum have been successfully used in suppressing weed growth and improving yield of crops such as wheat, maize and soybean with less cost (Ahmad, 1998; Khalq et al., 1999). Concentrated sorgaab (sorghum water extract) controlled Chenopodium album, Phalaris minor, Fumaria indica and Rumex dentatus in wheat crop. It offered 15-47 per cent and 19-49 per cent reduction in weed density and dry weight, respectively. Soil incorporation of sorghum mulch suppressed the Phalaris minor, Chenopodium album and reduced the weed dry weight (48-56%) and increased the yield (16-17%) of wheat over the control (Cheema and Khaliq, 2000). Spray of sorgaab (sorghum water extract) on cotton crop suppressed weed density by 13-54 per cent and weed dry weight by 87%. The weed biomass was suppressed in sorgaab (sorghum water extract), sorghum mulch and in herbicidal treatments by 40, 56 and 87 per cent, respectively. The seed cotton yield increased by 69 per cent (over control) in two sorgaab foliar sprays and 59 per cent in sorghum mulching (Cheema et al., 2000).

Pre emergence application of sorgab at 15 L ha$^{-1}$ + metalochlor 717 g a.i. ha$^{-1}$ controlled the 62-92 per cent purple nutsedge and reduced the purple nutsedge dry weight by 75-88 per cent (Javid and Cheema, 2008). Soil incorporation of sorghum stalks at 2, 4 and 6 t ha$^{-1}$ reduced
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Weed dry weight by 42, 48 and 56 per cent, respectively. Application of sorghum water extract in mungbean controlled Cyperus rotundus, Chenopodium album, Convolvulus arvensis and reduced the weed density (17.5-31.6%), weed dry weight (23.7-59.6%) and increased the yield (4.0-17.7%) compared to control (Cheema et al., 2001). Combined application of sorghum water extracts + isoproturon controlled Phalaris minor, Melilotus parviflorus and reduced the weed density (94.2%), weed dry weight (64.8%) and increased the yield (32.2%) of wheat over the control (Cheema et al., 2002).

Application of sorghum water extract in cotton controlled the Trianthema portulacastrum, Cynodon dactylon, Cyperus rotundus and reduced the weed density (47.0%), weed dry weight (29-40.1%) and increased the yield (17.7-59.0%) over the control (Cheema et al., 2002). Combined application of sorgaab with sunflower, Eucalyptus, sesame, Brassica and rice water extracts is more effective for weed management than the sole application of either water extract (Cheema et al., 2003b). Sorghum, sunflower and Eucalyptus (Cheema et al., 2003b), sesame, Brassica and rice (Rehman et al., 2010) water extracts have effectively controlled the weeds by reducing herbicide dose up to half of recommended one.

Khalq et al. (2002) observed that metolachlor at 1.15 kg ha⁻¹ sorgaab at 10 L ha⁻¹ and pendimethalin at 825 ml ha⁻¹ reduced the dry weed biomass by 78 and 75 per cent, respectively. Cheema et al. (2003a) showed that sorgaab at 6 L ha⁻¹ or 12 L ha⁻¹ combined with fenoxaprop - p - ethyl at 375 ml ha⁻¹ reduced the dry weed biomass by 87 per cent. The lower weed density, fresh weed biomass dry weed biomass and consequently the highest biological yield (7443 kg ha⁻¹) was observed in plots receiving full dose of pendimethalin at 825 g ha⁻¹. It was followed by sorgaab 18 L ha⁻¹ + sunflower 18 L ha⁻¹ + pendimethalin 413 ml ha⁻¹, where the biological yield was 7235 kg ha⁻¹. The lowest yield (6025 kg ha⁻¹) was recorded in the weedy check plots (Inayat et al., 2009).

Water extract of sorghum + application of pendimethalin controlled the Trianthema portulacastrum and reduced the weed density (51.9%), weed dry weight (50.3%) and increased the yield (3.5%) of cotton compared to control (Iqbal et al., 2009). Water extracts of sorghum + Brassica application of pendimethalin (Jabran et al., 2010) controlled the Trianthema portulacastrum, Cyperus rotundus, Chenopodium album, Coronopus didymus and decreased the weed density (42.8-91.3%), weed dry weight (37.4-94.1%) and increased the yield (39.9%) of canola over the control.

Sorghum reduced the density and biomass of Trianthema portulacastrum and Convolvulus arvensis (Khalli et al., 2010). Application of sorghum water extract in rice controlled Echinocloa colonum, Cyperus rotundus, Cyperus iria and decreased the weed dry weight (40.4%) and increased the yield (12.5%) over control (Wazir et al., 2011). It has also been successfully used against weeds of cotton, sunflower and mungbean. It increased the yield of these crops by 3-59 per cent depending upon the type of crop, frequency of application and time of application (Cheema et al., 2012). Application of sorghum shoot water extract at 10 ml kg⁻¹ soil significantly reduced the germination per cent, root length, shoot length, fresh biomass and dry biomass of Trianthema portulacastrum, Digera arvensis and Convolvulus arvensis (Kandhro et al., 2015).

Sunflower and Sesame

Sunflower is an annual oleaginous plant native to America has allelopathic activity against weeds (Bogatek et al., 2006). Its use as a natural herbicide for some broadleaf weeds has been suggested (Anjum and Bajwa, 2007 a, b). Several substances with allelopathic properties such as phenolic compounds, diterpenes, triterpenes have been isolated and chemically characterized (Macias et al., 2004b). The properties of sunflower are well recognized; their effects on many weeds and crops have been documented. Macias et al. (2004a) isolated 125 natural allelopathic compounds that are phytotoxic towards many plants from different sunflower cultivars. Heliannuols, terpenoids and flavonoids are the most important allelopathic compounds isolated from sunflower (Vyyyan, 2002).

The use of sunflower as green manure (Om et al., 2002) reduced the population of Phlaxis minor by 42 and 100 percent under field and laboratory conditions, respectively. Annuonone isolated from aqueous extract of sunflower (cv. Suncross-42 leaves) reduced the growth of Phlaxis minor, Chenopodium album, Coronopsis didymus, Medicago polymorpha, Rumex dentatus (Anjum and Bajwa, 2005). Sunflower extracts completely inhibited seed germination of white mustard (Bogatek et al., 2006). However, the phytotoxins did not affect the seed viability (Kupidlowska et al., 2006). Allelopathic chemicals from sunflower could influence the antioxidant system in target plants, causing cell-membrane permeability and cellular damage, reducing the ability of the target plants to germinate and causing a gradual loss of seed vigour (Oracz et al., 2007).

Emulsive water concentrate (EW) formulation of allelochemicals obtained from root exudates of sesame plants (Lalit and Varshney, 2008) applied on tubers of purple nut sedge caused significant delay and inhibition in germination. Emulsive water concentrate formulation at 240 µg g⁻¹ concentration in soil inhibited shoot length, shoot and root biomass by 89, 81.3 and 91.9 per cent, respectively over the control. Results of Awan et al. (2009) revealed that combined application of sorghum + sunflower water extracts + pendimethalin inhibited the Chenopodium album, Melilotus indica and reduced the weed density (84.0%), weed dry weight (67.3%) and increased the yield (16.4%) of sunflower compared to control. Application of water extract of sunflower controlled Avena fatua, Phalaris minor and reduced the weed dry weight (10-62.0%) and increased the yield (18.55-62.0%) of sunflower compared to control (Jamil et al., 2009).

Sunflower inhibited seed germination, growth and biomass of Trianthema portulacastrum (Mahmood et al., 2010) and Digera arvensis (Asgharipour, 2011). Soil
incorporation of sunflower + rice + Brassica in maize field (Khalil et al., 2010) inhibited the Trianthema portulacastrum and reduced the weed dry weight (60.1%) and increased the yield (41.0%) compared to control. Water extracts of sorghum + sunflower + rice in combination with butachlor in rice (Rehman et al., 2010) controlled Echinochloa crus-galli, Cyperus iria and Dactylolobium aegyptum, decreased the weed density (74-97%), weed dry weight (66-78%) and increased the yield (61%) of rice over the control.

Application of sunflower water extract in wheat controlled Avena fatua, Melilotus officinalis, Phalaris minor and Rumex obtusifolius, reduced the weed density (10.6-33.6%), weed dry weight (2.2-16.5%) and increased the yield (1.6-10.7%) over the control (Naseem et al., 2010). Combined application of sorghum and sunflower water extracts (Mubeen et al., 2012) drastically reduced the root length, shoot length, root dry weight and shoot dry weight of three weed species viz., Trianthema portulacastrum, Dactylolobium aegyptum and Euselina indica. Aqueous extracts from the leaf, stem and root of the sunflower at 100 per cent significantly reduced the germination percentage, plumule length and radical length of Parthenium and Amarthus (Monika and Satsangi, 2013).

Trees with allelopathic potential for weed control

Through allelopathy, trees can regulate the germination, growth and development of weeds. Ethanolic extracts of seeds of Annona squamosa, Carica papaya, Coffea arabica and Tamarindus indica were found to inhibit germination of Amarthus spinosus by 13, 58, 100 and 36 per cent, respectively (Rizvi et al., 1980). Eucalyptus species released volatile compound such as benzoic, cinnamic and phenolic acids which (Putnam, 1984) inhibit the growth of some crops and weeds near to it.

Eucalyptus leaf leachate and oil showed differential effects on the growth of weeds. The leaf leachate of 20 per cent concentration suppressed the biomass production of Cynodon dactylon by about 50 per cent, whereas 1.0 per cent oil caused 68 per cent reduction. Application of 1.0 per cent oil significantly inhibited shoot and root length, leaf chlorophyll and total biomass production of Cyperus rotundus (Babu et al., 1996). Eucalyptus spp., because of high allelopathic activity, is expected to control weeds (Kohl et al., 1998a). Aqueous extracts of its bark, leaves and oil inhibited Parthenium hysterocephorus (Kohl et al., 1998b).

Dried mango leaf powder completely inhibited sprouting of purple nutsedge tubers (James and Bala, 2003). According to Khan et al. (2004), Prosopis, Eucalyptus and Acazia retarded the growth and development of several weeds. Application of 5 ml of aqueous extract of Eucalyptus camaldulensis leaves (Khan et al., 2008) significantly lowered fresh and dry weight of Convolvulus arvensis and other weeds in contrast to water application. Aqueous leachates of fresh leaves of Eucalyptus significantly reduced the initiation of propagules and early growth of Cyperus rotundus seedlings (Ranganathan and Kandasamy, 2008).

El-Rokiek and Eid (2009) documented that aqueous extracts of fresh and dry leaves of Eucalyptus citriodora reduced the germination and seedling growth of wild oat (Avena fatua L.). Studies on the allelopathic effects of Eucalyptus camaldulensis on seed germination and seedling growth of Acroptilon repens, Plantago lanceolata and Portulaca oleracea (Dadkhah and Asadi, 2010) revealed that maximum inhibition of germination percentage, rate of germination and seedling growth were recorded when using the higher concentration of the aqueous extract (20 g L⁻¹) of Eucalyptus leaves.

El-Rokiek et al. (2010) observed that application of mango leaf extract at 25 per cent or leaf powder at 100gkg⁻¹ of soil reduced the number of mother shoots tuber⁻¹, number of leaves of mother shoots tuber⁻¹, length of mother leaves, number of daughter shoots tuber⁻¹ and number of leaves of daughter shoots tuber⁻¹, length of basal buds and tubers, number of rhizomes tuber⁻¹, length of rhizomes, dry weight of foliage, dry weight of underground, total dry weight and increased the total phenol contents in foliage and underground parts of purple nutsedge compared to control. Shoot aqueous extract of Eucalyptus, sunflower and sugarcane (Dadkhah, 2012) caused inhibition in germination, growth and photosynthesis of the Amarthus rutifex. Aqueous extracts of old mango leaves reduced the germination, shoot length, root length and dry weight by 95, 96, 93 and 95 per cent, respectively (Kamran et al., 2013). Volatile essential oil of Eucalyptus possess strong inhibitory potential against Cyndon dactylion and Amarthus blitoides that could be exploited for weed management and can be recommended as a biological herbicide with the aim of weed control (Rassael et al., 2013). Aqueous leaf extracts of Eucalyptus camaldulensis inhibited the germination and growth of Datura spp., Sonchus spp. and Sinapis spp. (Saed et al., 2013). Leaf extract of Eucalyptus globules significantly decreased the germination percentage, root and shoot length and fresh and dry weight of Solanum nigrum (Reza et al., 2014). Eucalyptus powder at 30 g kg⁻¹ soil + Eucalyptus water extract at 30 ml kg⁻¹ soil significantly reduced the root length, shoot length, fresh and dry weight of Cyperus rotundus and Convolvulus arvensis (Kandhro et al., 2016).

CONCLUSION

From this review it can be concluded that, application of allelochemicals through water extract, intercropping, cover cropping and mulching is promising method to control weeds and enhance crop production. However, more work is needed to test the allelochemicals present in the crops and trees.

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