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INTEGRATION OF ALLELOPATHY AND LESS HERBICIDES EFFECT ON WEED MANAGEMENT IN FIELD CROPS AND SOIL BIOTA : A REVIEW

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Abstract

Weeds cause serious yield reductions and lower the productivity of field crops worldwide. Chemical control is an efficient method to control weeds, and herbicides account for two third of total pesticide usage in the world. Nevertheless, continuous and indiscriminate use of synthetic herbicides in heavy doses is creating hazardous effects related to environment and an alarming number of herbicide-resistant weeds. Hence, it is imperative to find out some natural practice or method to control the weeds. Allelopathy has been found to offer eco-friendly approaches which can be used for controlling weeds effectively with least environmental concerns. Application of allelopathic crop extracts and residues is among the promising practical strategies for this purpose. However, in most cases, allelopathic extracts or crop residues provide limited weed suppression, and most often suppression in weed growth are not comparable to those achieved with labeled herbicide dose. Therefore, other methods that help increase the efficacy of allelopathic extracts or residues may be critical to enhance weed suppression while reducing our reliance on herbicides. Substantial scope exists to reduce the herbicide rate when lower rates of herbicides are applied in combination with aqueous extracts or residues of different allelopathic crops without any yield penalty. Moreover, the incorporation of crop residues also improves soil health with many implications on soil biota. The present article reviews the work concerning the combined effect of allelopathic water extracts and residues with lower rates of different herbicides on weed management and beneficial soil microorganisms in different cropping systems. Although this approach cannot discard use of synthetic herbicides completely but their use can be reduced up to a certain extent by utilizing allelopathy as an alternative weed management strategy for crop production as well as environmental benefits. The other advantages of this approach on soil properties are discussed. Some future lines of work are also suggested in this regard.

***Keywords*:** Allelopathy, herbicides, integration effect, weed control, soil biota, crop production.

Introduction

Weed infestation in field crops is principal cause of direct loss in quality and quantity of yield produce. Weeds have been tagged as the omnipresent class of pests interfering with crop plants through competition and allelopathy (Weston and Duke, 2003). Traditionally, weed management practices includes preventative, cultural, mechanical, biological, and chemical tactics (Harker and O'Donovan, 2013). However, with the rapid increase in the number of effective herbicides after 1960's, weed management in modern agriculture have been reliant on herbicides. Weed management programs have often been uncoupled with ecology, and the overdependence and irrational use of herbicides during the last 40 years has led to many associated problems. There are reports that document soil, water and aerial pollution owing to herbicides (Khaliq and Matloob, 2011; Yun and Choi, 2002). Herbicide residues in food are reported to deteriorate food quality and enhanced the risk of diseases [89]. Indiscriminate use of herbicides has also led to the evolution of herbicide resistance in weeds (Heap, 2012; Macias *et al.*, 2007; Yun and Choi, 2002). Growing public awareness in recent past about quality of life has led to concerted efforts on search for alternative methods of weed control. Although herbicide use cannot be eliminated due to escalating demand for food for an ever-increasing world population, the use of herbicides may be reduced through using integrated weed management approaches in field crops (Anderson, 2007; Bishop *et al.*, 2006). Integrating weed control practices with cultural measures can have a broader impact on weeds when manipulated with other crop production practices influencing agro-ecosystems. Such measures comprise of planting time, (surface or incorporated) mulching, intercropping, row spacing and seeding densities, just to name a few. The adoption and execution of an integrated approach of available weed management practices have been advocated to combat weed menaces and prevent any change in weed community structure (Maity and Mukherjee, 2008). In modern agriculture, field crops, especially, the cereals, are planted in distinct rows with variable row spacing and plant densities (Chen *et al.*, 2008; Khaliq *et al.*, 2014). Manipulation of crop row spacing and its orientation has been suggested as a mean to reduce light interception by weeds (Chauhan, 2000). Allelopathy is suggested to offer a great prospective to manage weeds. Different strategies in which allelopathy is involved have been suggested such as using allelopathy in crop rotations, cover crops and mulches, smother crop, crop mixtures and intercropping and use of allelopathic crop residues or extracts (Cheema and Khaliq, 2000; Cheema *et al.*, 2004; Singh *et al.*, 2003). Allelopathic crop residues as mulch or incorporated into field soil have been found to be the most successful strategy in weed suppression (Alsaadawi *et al.*, 2013; Jones *et al.*, 1999; Kumar and Goh, 2000; Moody, 1995; Wilson, and Foy, 1990). However, in most cases, the efficacy of allelopathic residues was generally lower than herbicides. Therefore, many researchers have discussed the possibility of integrating allelopathic residues with other managing options for weed control. Bhowmik and Inderjit (2003) and Mushtaq *et al.* (2010) suggested that the herbicides applied in combination with allelopathic conditions could enjoy a complementary interaction, and may help to minimize herbicide usage for weed management in field crops.

This review compiles the achievements from the direct and indirect effects of the integration of allelopathic residues of different crops with reduced rates of different herbicides on weed management and crop production. It also critically reviews the developments on the use of allopathic plant aqueous extracts for minimizing reliance upon herbicides.

Integrative effect of allelopathic crop residues and less herbicides

Left over material for decomposition after harvesting and threshing of a field crop are referred to as crop residues (Kumar and Goh, 2000). It is a valuable natural resource that has many potential uses in agroecosystems among which is imparting weed suppression through physical hindrance and chemical effects (allelopathy). Residues of many field crops are allelopathic and exhibit toxicity during decay (Chou,1999). The underlying principle for weed management using crop residues is the release of inhibitory allelochemicals in their immediate vicinity that exert adverse effects on germination and seedling growth of a number of agricultural weeds (Batish *et al*., 2001). Hence, crop residues can be used for weed control as a step towards sustainable weed management strategy (Alsaadawi *et al*., 1986; Cheema *et al*., 2012).

(i) Effect on weed management and crop production

Allelopathic crop residues used as mulch or incorporated into field soil offer the most effective strategies in weed suppression (Putnam, 1990; Putnam and DeFrank, 1979; Weston and Duke, 2003). Nonetheless, the level of weed suppression achieved is not comparable to that realized with label rate of herbicides. Looking for methods that help increase the efficacy of allelopathic residues may be critical for both enhancing weed suppression as well as reducing our reliance on herbicides. An alternative practical and feasible approach for weed management has been developed where the residues of allelopathic crops have been left to dry under field conditions and then promptly incorporated into production sites with low herbicide doses. Alsaadawi *et al.* (2011) found that application of trifluralin herbicide at 50% of recommended dose with sunflower residue incorporation at 600 g m^{-2} efficiently reduced the total weed count and weed dry biomass accumulation in field plots of faba beans and this treatment combination was as effective as sole application of the label rate of herbicide regarding weed suppression and crop yield (Table 1).

Influence of sorghum residues and reduced rate of trifluralin herbicide was evaluated for suppression of weeds in broad bean (Alsaadawi *et al*., 2013). Application of 3.5, 5.3 and 7.6 t ha^{-1} of sorghum residue with 50% label rate of herbicide provided weed suppression similar or even more than that achieved with sole application of recommended dose of trifluralin (Table 2). Additionally, integration of half dose of trifluralin with sorghum residues at the test rates furnished seed yield similar or better than the label rate of herbicide (Alsaadawi *et al*., 2013). These authors further observed poor emergence and growth of weeds early in the growing season that started growing normally later but could not compete with faba bean. Periodic analysis of soil phenolics indicated the presence of several phytotoxic phenolic acids (Al-Obaidi and Alsaadawi, 2015). Maximum quantities of total phenolics coincided with the period in which maximum suppressive activity against weeds was noticed under field condition, and hence explains the activity of phytotoxins against weeds.

Application of half label dose of trifluralin in field plots amended with sunflower residues at 6.3 t ha^{-1} provides weed suppression and mung bean seed yield similar to that achieved by the label rate of trifluralin (Tawfiq. and Alsaadawi, 2015). Alsaadawi and Sarbout (2015) reported that the level of suppression of weeds and improvement in seed yield of cowpea from the combined application of sunflower residue at 6 t ha^{-1} with half dose of trifluralin was similar to that achieved with label dose of herbicide. Bioassay studies revealed that soil amended with sunflower residues at different periods of decomposition exhibited a significant suppression of seedling emergence of *Echinochloa colonum* (L.) Link, and *Portulaca oleracea* L. and such suppression was highly correlated with the phenolic content of the soil.

Integrative effect of allelopathic crop residues was also reported for post emergence herbicides. Alsaadawi and Al-Temimi (2011) evaluated the allelopathic potential of sunflower residues (600 and 1400 g m^{-2}) in combination with reduced doses of post mergence herbicides (2,4-D and Topic) at 50 and 75% of their respective label doses) against dry weed biomass in barley. Spraying of 50% label dose of herbicides in plots containing sunflower residues at 600 g m^{-2} resulted in similar weed suppression and barley grain yield as recorded with label dose of both the herbicides.

Sorghum residues in combination with reduced rate of post emergence Chevalier herbicide (mesosulfuron and iodosulfuron) were evaluated for their efficacy to control weeds in a wheat production system. Sorghum residues at 3.5 and 5.3 t ha^{-1} gave similar weed suppression and wheat grain yield as observed for label rate of herbicide used alone (Lahmood and Alsaadawi, 2014). Nonetheless, soil incorporation of higher rate of sorghum residue (7.6 t ha^{-1}) significantly not only inhibited density and dry biomass of weeds but also reduced the yield of wheat as compared with full dose of herbicide suggesting the inhibitory effects of higher rate of sorghum residues on wheat growth. Sorghum residue incorporated in soil delayed emergence of wheat and thus reduced its grain yield (Roth *et al*., 2000).

Al-Eqaili *et al*. (2015) reported that combination of sunflower residues at 3 and 6 t ha^{-1} with half dose (300 g ha^{-1}) of Chevalier 15 WG herbicide suppressed weed density and biomass more than that recorded with the application of residue alone at same rates. The combined application of sunflower residues with reduced herbicide recorded grain yield that was similar to that achieved with label rate of herbicide**.** The increase in grain yield was attributed mainly to enhanced number of spikes per plant**.**

(ii) Effect on mycorrhizal association

Mycorrhiza is a symbiotic relationship between special soil fungi and fine plant roots. Since the association is mutualistic, both organisms benefit from the association. The plant and fungi get several benefits from this association such as direct access of fungi to carbohydrates produced by the plant in photosynthesis (Maria, 2005), increase overall absorption capacity of roots by increasing surface area (Selosse *et al*., 2006), mobilization and transfer of nutrients (P, N, S, Cu, Zn) from the soil to the plant (Li *et al*., 2006), establishment, nodulation and atmospheric nitrogen fixation capacity in legumes, tolerance of roots to soil-borne pathogens such as nematodes or phytopathogenic fungi such as *Fusarium oxysporum, Fusarium solani, Rhizoctonia solaniand Macrophomina*, production of plant growth hormones (such as cytokinins and gibberellins) and compete or antagonize pathogenic microorganisms (Muchovej, 2009).

The symbiotic relationship between mycorrhiza and host plant can be seriously hampered by many factors including pesticides mainly the herbicides (Trappe *et al.*, 1984). Several authors have reported different effects of herbicides on VAM symbiosis, which ranges from no adverse effects to slightly or highly toxic effects and this range of variation has been found to be host plant and herbicide specific and dosage-dependent (Dodd. and Jefferies, 1989; Ocampo and Barea, 1985; Pellet and Sieverding, 1986). Also, mycorrhizal association is reported to be affected by allelopathy and the effect is either stimulatory, no effect or inhibitory, and such effects depend on host species, type of allelochemicals and their concentration (Javid, 1999). Chabot *et al.* (1992) reported that at 2% CO_2, flavonols kaempferol, quercetin and morin improve spore germination and hyphal growth of *G. margarita*, while biochanin A, genistein, hesperetin, galangin and chrysin inhibited the hyphal growth. Other authors reported that several phenolic compounds act as signal molecules or mediate signal transduction pathways in symbiotic systems (Lynn and Chang, 1990). Plant extracts of the *Artemisia princeps* var. *orientalis* and garlic mustard (*Alliaria petiolata*) were found to stimulate or inhibit mycorrhizal association (Roberts and Anderson, 2001; Yadav and Mohan, 1982).

The combination of allelopathy and lower rate of herbicide not only suppressed weed population and dry biomass but also increased mycorrhizal population in soil and thereby improved crop growth. Al-Eqaili *et al.* (2014) found that application of label rate of Chevalier drastically reduced sporulation but did not affect colonization rate and intensity of *Glomus mosseae*, whereas sunflower residues incorporated in soil at 3 and 6 t ha^{-1} significantly increased sporulation and colonization rate and intensity. However, combination of lower rate of herbicide with sunflower residues at 6 t ha^{-1} provided better sporulation and colonization rate as compared to sole application of herbicide. Thus it appears that allelopathic residues mitigate the negative effect of Chevalier herbicide on sporulation and colonization rate of *G. mosseae* (Al-Eqaili *et al.*, 2014). Sarbout *et al.* (2015) studied the influence of pre-emergence trifluralin in combination with sunflower residues on sporulation and colonization rate and intensity of *G. mosseae* Application of half dose of herbicide and sunflower residue at 6 t ha^{-1} improved these mycorrhizal traits as compared to sole application of label rate of herbicide.

(iii) Effect on soil nitrification

Nitrification is a biological oxidation of ammonia to nitrite and then nitrate. Because nitrate and nitrite are much more mobile in soils than ammonium, nitrification can be viewed as a process that mobilizes nitrogen, making it more available for uptake by plants but potentially allowing it to leach beyond root zone (Nelson and Huber, 1980). The NO_3 may be lost through percolation of soil water or volatilization as nitrogen gas or nitrogen oxides through denitrification process (Katyal *et al.*, 1985; Mikkelsen *et al.*, 1978). Loss of N due to leaching or denitrification in addition to other ways of N losses from soil results in very poor recovery of applied nitrogen (Rankin, 2011; Rice, 1984; Yadav and Mohan, 1982). This suggests that inhibition of nitrification would help in nitrogen conservation. As reduction of nitrate to ammonium requires energy, inhibition of nitrification would also conserve energy.

Allelopathy is reported to affect the process of nitrification. Low nitrification rates in a ponderosa pine (*Pinus ponderosa*) forest were ascribed to direct inhibition by monoterpenes leached from pine litter (White, 1986). Nonetheless, Bremner and McCarty (1993) postulated that the low nitrification rates were due to the presence of phenolics, tannins and monoterpenes, which initiate heterotrophic immobilization of NH_4^+ that resulted in decreased availability of NH_4^+ for nitrifying bacteria and thus lowered the nitrification rates. Paavolainen *et al.* (1998) reported increased microbial respiration and decreased nitrification in Norway spruce (*Picea abies*) forest after addition of monoterpenes in the soil. Residues and root exudation of plant species that dominate some of the climax ecosystems produce allelochemicals that inhibit nitrification and nitrifying activity and the degree of inhibition appears to increase with the ecosystem's maturity (Donaldson and Henderson, 1990b, Donaldson and Henderson, 1990a , 60, 86). Among the inhibitory compounds, phenolics and terpenoids have received most of the attention (Subbarao *et al.*, 2006). Water extracts and residues of sorghum and sunflower cultivars were found to inhibit the soil nitrification, and such reductions were prominent in highly allelopathic cultivars (Al-Eqaili *et al.*, 2015; Alsaadawi *et al.*, 1985, 1986). Ward *et al.* (1997) reported allelopathic inhibition of nitrification in pure cultures of nitrifying bacteria in presence of redwood (*Sequoia sempervirens*) monoterpenes, but not of glucose (Krummel and Harms,1982), the later eliminating the possibility of heterotrophic competition. Strauss and Lamberti (2002) suggested that both mechanisms function concurrently: high quality carbon induces competition between heterotrophic and nitrifying bacteria for NH_4 and some functionality of nitrifying bacteria is hindered via direct allelopathy from certain compounds in litter leachate.

Beside allelopathy, herbicides are also reported to affect the nitrification rate, however, such effect varies with type of herbicide, method of application, concentration used, soil properties and the environmental conditions. Nitrification rates were inhibited by some herbicides including chlorthiamid and 2, 4, 5-T, 2, 4-D Na salt, amitrole, chlorpropham, 2,4-D amine, dinoseb, propham and propanil, while pendimethallin application stimulated nitrification process. Incorporation of 2,4-D into the soil reduced the nitrification, but surface application did not influence it (Olson and Lindwall, 1991). Nagaraja *et al.* (1997) reported that the nitrification process was inhibited by atrazine and the inhibition increased with increased concentration of atrazine. Martens and Bremner (1994) reported that inhibitory effect of 18 herbicides tested on nitrification of urea N in soil increased with a decrease in the organic matter content and an increase in the sand content of the soil. However, little is known regarding the combined effect of herbicides and allelopathy on soil nitrification. Sarbout and Alsaadawi (1993) tested the effect of trifluralin in combination with sunflower residues on nitrification under controlled condition. They incubated soil amended with $(NH_4)_2\ SO_4$ as a substrate and sunflower residues at 3 and 6 t ha^{-1} alone and in combination with 50% dose of trifluralin. Rate of nitrification was measured every 4 days for 4 weeks. They found that nitrification was started at 4-day of incubation and increased considerably until reach maximum at 28-day of incubation where 79-89% of NO_3 was produced by the test treatments due to oxidation of ammonium. Incorporation of both sunflower residues rates alone and in combination with reduced dose of trifluralin significantly reduced the nitrification rate over control (without sunflower residues) at all incubation periods. In almost all incubation periods, inhibition of nitrification by sunflower residues at 6 t ha^{-1} was maximum followed by combination of this residue rate with reduced dose of trifluralin. Additional work on other herbicides in combination with residues of allelopathic crops is recommended to find out the possibility to invest this approach in regulating the availability of NO_3 for crops.

Integrative effect of allelopathic crop extract and less herbicides on weed management and crop production.

Several studies have indicated that the water extracts of various field and forest crops can be used as potential herbicides when combined with reduced doses synthetic herbicides (Table 3). Research conducted on various crops including rice, cotton, wheat, mungbean and maize have indicated the potential of effective weed control and improve crop production with the reduced herbicide dose in combination with allelopathic water extracts. Brief summary of such findings narrates as follows.

(i) Rice (*Oryza sativa* L.)

In rice, application of concentrated sorghum water extract (sorgaab) with reduced doses of ethoxysulfuron (Sunstar 15 WG) reduced the density and dry weight of purple nutsedge (*Cyperus rotundus* L.), wild rice (*Echinochloa Colona* [L.] Link) and barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv.] by 73.18-74.32%, and 76.94-77.00% respectively, and enhanced the paddy yield by 1.14-10.29% than weedy check (Cheema *et al.*, 2005a). The maximum reduction in weed density and dry weight was observed when concentrated sorgaab (12 L ha^{-1}) was combined with ethoxysulfuron (Sunstar 15 WG; 10 g a.i. ha^{-1}). In this study, combination of sorgaab with reduced dose of butachlor (Machete 60 EC) reduced the density and dry weight of all three weeds by 58.99-62.83%, and 67.93-76.71%, respectively than weedy check, with yield increase of 8.57-12.57%. In this study, the label rate of ethoxysulfuron (25-30 g a.i. ha^{-1}) reduced the density and dry weight of all weeds by 70.12 and 67.47% of weedy check and enhanced grain yield by 10.95% and the corresponding reduction in density and dry weight of all weeds was 52.99% and 65.05% over weedy check where full dose of butachlor (1150-1200 g a.i. ha^{-1}) was used. Application of Butachlor at standard dose also enhanced the grain yield by 9.81% (28). In another study, Rehman *et al.* (2013) found that combination of sorghum, sunflower and rice water extracts with reduced dose of bispyribac-sodium (Nominee10SC) reduced the density and dry weight of barnyard grass, rice flatsedge (*Cyprus iria* L.), fleabane (*Conyza stricta* Lees.) and crowfoot grass (*Dactyloctenium aegyptium* (L.) Willd.) by 29.98-37.25%, and 25.32-35.83%, respectively, and improved the paddy yield by 12.94-19.04% compared with weedy check.

In another study, application of rice, and sorghum + sunflower water extract in combination with reduced dose of penoxsulam (Ryzelan 240SC) reduced the density and dry weight of crowfoot grass by 35-46%, and 45-52% respectively than the weedy check. Full dose of penoxsulam (Ryzelan 240SC; 15 g a.i. ha^{-1}) reduced the weed density and dry biomass by 54 and 46% of weedy check (Cheema *et al.*, 2010). Wazir *et al.* (2011) also reported 34.76% reduction in the density of different rice weeds when sorghum water extract was applied with reduce dose of Ryzelan.

(ii) Mungbean (*Vigna radiata* [L.] R. Wilczek)

In mungbean, application of concentrated sorgaab with reduced dose (1.15 kg a.i. ha^{-1}) of S- metolachlor decreased weed dry weight by 79.32%, and enhanced seed yield of mungbean by 32% than weedy check. The level of reduction in weed dry biomass with standard dose of S-metolachlor (2.3 kg a.i. ha^{-1}) was 40.33% with a yield increment of 14% (Khaliq *et al.*, 2002). When concentrated sorgaab was combined with reduced dose of pendimethalin (165 g a.i. ha^{-1}), reduction in weed dry weight and improvement in seed yield of mungbean was 75.50% and 24.85%, respectively than weedy check. Standard dose of pendimethalin (330 g a.i. ha^{-1}) reduced weed dry weight by 62.65%, whilst increased the grain yield by 25%, compared with weedy check (Khaliq *et al.*, 2002).

(iii) Maize (*Zea mays* L.)

Application of sorghum, sunflower, brassica (*Brassica compestris* L.) and mulberry (*Morus alba* L.) water extracts with reduced dose of atrazine decreased the density of horse purslane (*Trianthema portulacastrum* L.) by 9.02-20.90% than control (Khan *et al.*, 2012) with a concomitant reduction of 85.77-90.30% in dry weight of horse purslane, and an increase of 21.45-36.19% in grain yield of maize (Khaliq *et al.*, 2002). The maximum reduction in the density and dry weight of horse purslane, and highest improvement in maize grain yield was recorded when sorghum, sunflower, brassica and mulberry extract (each at 20 L ha^{-1}) was combined with atrazine (250 g a.i. ha^{-1}), while such reduction with standard dose of atrazine (500 g a.i. ha^{-1}) was 38.11 and 94%, respectively over weedy check, with 49% increase in grain yield [l53]. In another study, combined application of sorgaab with reduce doses of atrazine helped to suppress horse purslane, field bindweed, and purple nutsedge; and this combination was as effective as the standard dose of atrazine (Cheema *et al.*, 2013). Latifi1 and Jamshidi (2011) further reported that application of sorgaab in combination with furansulfuron reduced the density of various weeds by 57.33% than control.

(iv) Canola (*Brassica napus* L.)

Application of sorghum water extract with either brassica or rice water extract in combination with the reduced dose of pendimethalin reduced the density and dry weight of horse purslane, purple nutsedge, common lambsquarters (*Chenopodium album* L.), and swine cress (*Coronopus didymus* [L.] Sm.) by 45.71-74.69%, and 67.10-78.28%, respectively than the weedy check (Jabran *et al.*, 2008, 2010). The maximum reduction in the density and dry weight of these weeds was observed with the combined application of sorghum and rice water extracts (each at 15 L ha^{-1}) with pendimethalin (0.6 kg a.i. ha^{-1}). This was comparable with reduction in total weed density and dry biomass (61.23 and 56.54%, respectively) achieved with standard dose of pendimethalin (1200 g a.i. ha^{-1}) when compared with weedy check (Jabran *et al.*, 2010). In another study on canola, mixed application of sorghum water extract with either brassica, sunflower or rice water extracts in combination with reduce dose of pendimethalin reduced the density and dry weight of purple nutsedge, horse purslane, lambsquarters and swine cress by 29.51-66.21% than weedy check as against 46 and 45.39% reduction in total weed density and dry biomass, respectively with the application of pendimethalin (1200 g a.i. ha^{-1}). The later also enhanced seed yield by 35.99% over weedy check (Jabran *et al*., 2008). Weed dry weight was reduced by 44.93-63.99%, and seed yield of canola was enhanced by 19.99-39.99% than weedy check in these studies. They further concluded that maximum reduction in the density and dry weight of these weeds was observed when sorghum and rice water extracts (each at 15 L ha^{-1}) were combined with pendimethalin (600 g a.i. ha^{-1}).

(v) Cotton

Several studies have reported the influence of combined application of allelopathic water extracts and reduced doses of herbicides on weed dynamics and seed cotton yield (Cheema *et al*., 2000, 2005b, 2002; Iqbal *et al*., 2009). Cheema *et al.* (2002) reported 15-50% reduction in the horse purslane and purple nutsedge densities, and 41-72.2% increase in seed cotton yield with combined application of sorgaab and reduced doses of S-metolachlor (Dual Gold 960 EC), pendimethalin (Stomp 330 EC) and trifluralin (Treflan 4EC). The maximum reduction in the weed density and improvement in seed cotton yield was observed when concentrated sorgaab (12 L ha^{-1}) was applied in combination with pendimethalin (Stomp 330 EC; 0.5 kg a.i. ha^{-1}). In a similar study on cotton, a decrease of 48.33-68.68% in density and 72.51-85.17% in dry weight of horse purslane and purple nutsedge was observed with combined application of sorgaab and reduced dose of pendimethalin that also enhanced the seed cotton yield by 7.61-31.52% than weedy check. Maximum reduction in weed density and dry weight was observed when sorgaab (12 L ha^{-1}) was applied in combination with pendimethalin (833 g a.i. ha^{-1}). Standard dose of pendimethalin (1250 g a.i. ha^{-1}) reduced the total weed density and dry biomass by 69.07 and 80.74% respectively over weedy check and enhanced seed cotton yield by 15.59% of weedy check (Cheema *et al*., 2005b). In another study on cotton, Iqbal *et al.* (2009) reported that application of sorgaab with either brassica or sunflower water extracts in combination with reduced dose of glyphosate decreased the density and dry weight of purple nutsedge by 86.26-94.75% and 85.96-95.21%, respectively than weedy check. In this study, they also found 12.97-19.40% increase in seed cotton yield due to combined application of these water extracts with reduced dose of glyphosate. In this regard, highest decrease in weed density and dry weight and maximum improvement in seed cotton yield was recorded when sorgaab (18 L ha^{-1}) and brassica water extracts (18 L ha^{-1}) were applied in combination with glyphosate (767 g a.i. ha^{-1}). Contrarily, full dose of glyphosate (2.3 kg a.i. ha^{-1}) reduced the total weed density and dry biomass by 96.57 and 96.92% respectively over weedy check and enhanced seed cotton yield by 21.77% of weedy check (Iqbal *et al*., 2009).

Likewise, Cheema *et al.* (2005b) tested the efficacy of combined application of sorgaab with reduced doses of pendimethalin and S-metolachlor in cotton. They found 41.80-45.90% decrease in density, and 49.34-67.85% decrease in dry weight of horse purslane and purple nutsedge with application of concentrated sorgaab along with reduced doses of these herbicides. Maximum reduction in weed density was recorded when concentrated sorgaab (10 L ha^{-1}) was applied in combination with pendimethalin (500 g a.i. ha^{-1}); while the highest decrease in weed dry weight was recorded when same level of concentrated sorgaab was applied with pendimethalin (667 g a.i. ha^{-1}). Standard doses of pendimethalin (1000 g a.i. ha^{-1}) and S-metolachlor (2000 g a.i. ha^{-1}) reduced the weed density and dry weight in the range of 52-68% and 45-57%, respectively over weedy check (Cheema *et al*., 2003b).

(vi) Wheat (*Triticum aestivum* L.)

Combined application of either of rice, congress weed (*Parthenium hysterophorus* L.), common reed [*Phragmites australis* (Cav.) Trin. ex Steud.] or *Datura alba* L. extract with reduced doses of Puma super (750EW) and Buctril super (600EC) reduced the weed density in wheat by 56.36-75.94%, compared with control (Table 3) (Afridi *et al*., 2014). The maximum reduction in weed density was recorded where congress weed allelopathic water extract (500 kg ha^{-1}) was applied in combination with Puma super (625 ml ha^{-1}). Half dose of Puma super (625 ml ha^{-1}) and Buctril super (375 ml ha^{-1}) when applied alone suppressed weed density by 32.09 and 28.53%, respectively over weedy check (Table 3; 1). In another study, Razzaq *et al.* (2012) reported that combination of sorghum and sunflower water extract with reduced dose of metribuzin (Sencor 70 WP), isoproturon (Cleaner 70 WP), idosulfuron (Atlantis 12 EC), phenoxaprop (Bullet 38 SC) and idosulfuron (Atlantis 3.6 WG) decreased the density and dry weight of swine cress and littleseed canarygrass (*Phalaris minor* Retz.) in wheat crop by 83.33-88.24%, and 77.94-92.86%, respectively, with yield advantage of 20-34.29% than weedy check (Table 3). In this regard, maximum reduction in weed density was observed when sorghum and sunflower water extract (each at 18 L ha^{-1}) was applied in combination with bensulfuron + isoproturon (Cleaner 70 WP; 315 g a.i. ha^{-1}). However, highest reduction in weed dry weight was recorded with sorghum and sunflower water extracts (each at 18 L ha^{-1}) in combination with mesosulfuron + idosulfuron (Atlantis 12 EC; 36 g a.i. ha^{-1}) (Table 3). Application of label dose of metribuzin (175 g a.i. ha^{-1}), bensulfuron + isoproturon (1050 g a.i. ha^{-1}), metribuzin + phenoxaprop (190 g a.i. ha^{-1}), mesosulfuron + idosulfuron (Atlantis 12 EC; 120 g a.s. ha^{-1}), mesosulfuron + idosulfuron (190 g a.i. ha^{-1}) reduced the weed density and dry weight by 81.37-96.08% and 85.71-93.49%, respectively than weedy check with yield advantage of 13.33-24.76% (Table 3) (Razzaq *et al.,* 2012).

Earlier, Jamil *et al.* (2005) observed a reduction of 53-91.17% in density, and 42.10-93.04% in dry weight of weeds in wheat crop due to combined application of sorgaab with reduced dose of isoproturon. Weed suppression enhanced the crop and a yield increase of 27.31-79.18% was recorded due to application of sorgaab with reduced dose of isoproturon (Table 3). In these studies, the maximum reduction in weed density and dry weight, and the highest improvement in wheat grain yield was recorded when concentrated sorgaab (12 L ha^{-1}) was applied with isoproturon (600 g a. i. ha^{-1}) and this was comparable with reduction in weed growth achieved with label dose of isoproturon (1000 g a.i. ha^{-1}) (Table 3) (Jamil *et al.* (2005).

Likewise, Sharif *et al.* (2005) found that the density and dry weight of wild oat (*Avena fatua* L.), purple nutsedge, and common lambsquarters in wheat was reduced by 60.93-80.60%, and 11.94-79.28%, respectively with yield increase of 5.17-18.65% with combined application of sorgaab and reduced doses of mesosulfuron methyl (Atlantis 3WG), bromoxinil + MCPA (Buctril super 60EC), isopruturon (Tolkan 50W) and bromoxinil + MCPA (Buctril M 40EC) (Table 3). Maximum reduction in weed density was observed when concentrated sorgaab (12 L ha^{-1}) was applied in combination with isopruturon (Tolkan 50W; 500 g a.i. ha^{-1}); while the highest decrease in weed dry weight was recorded when same level of concentrated sorgaab was applied in combination with reduced dose of mesosulfuron methyl (Atlantis 3WG; 6.25 g a.i. ha^{-1}). Application of mesosulfuron methyl (10.8 g a.i. ha^{-1}), bromoxinil + MCPA (375 g a.i. ha^{-1}), isoproturon (1000 g a.i. ha^{-1}) and bromoxinil + MCPA (500 g a.i. ha^{-1}) reduced weed density and dry biomass by 72-85 and 47-87 %, respectively over weedy check with yield advantage of 9.44-19% (Table 3) (Sharif *et al.*, 2005).

Application of lower doses of Atlantis (3.6 WG) in combination with sorghum, sunflower and mulberry water extract reduced the density of littleseed canarygrass, wild oat, lambsquarter, and black clover (*Medicago polymorpha* L.) by 66.82-85.87% and dry weight by 74.57-88.16%, respectively with a yield enhancement of 19.25-36.15%, which was comparable with weed reduction and yield advantage achieved with label dose of Atlantis (Table 3) (Mahmood *et al.*, 20013). Likewise, the combined application of sorghum, brassica and sunflower water extract at two variable rates with reduced dose of bromoxynil + MCPA decreased the density and dry weight of field bindweed (*Convolvulus arvensis* Retz.), sun spurge (*Euphorbia helioscopia* L.), and white-flowered sweet clover (*Melilotus alba* L.) by 80.63-90.54%, and 94.31-99.94, respectively than control; and enhanced the grain yield of wheat by 7.69-35.17% (Iqbal *et al.*, 2010) (Table 3). The highest reduction in weed density and dry weight and maximum improvement in wheat grain yield was recorded when sorghum, brassica and sunflower water extracts (each at 18 L ha^{-1}) were applied in combination with bromoxynil + MCPA (50 g a.i. ha^{-1}). Reduction in weed density and dry biomass was 78.57 and 96.37%, respectively when label dose of Bromoxynil + MCPA (100 g a.i. ha^{-1}) was used alone (Table 3) (Iqbal *et al.*, 2010).

Recently, Elahi *et al.* (2011) also reported that application of sorghum, sunflower, brassica and rice water extract in various combinations with reduced doses of phenoxaprop-p-ethyl and isoproturon suppressed the density and dry weight of swine cress and sour clover (*Melilotus parviflora* Desf.) by 12.16-96.55%, and dry weight by 39.16-98.79%, respectively than weedy check. Yield increase of 10.29-22.79% was also recorded by these authors (Table 3). Application of standard dose of isoproturon (1000 g a.i. ha^{-1}) reduced the weed density and dry weight by 98.94 and 97.59%, respectively over weedy check with yield advantage of 30%. While standard dose of phenoxaprop-p-ethyl (862 g a.i. ha^{-1}) reduced the weed density and dry weight by 26.20 and 63.05% respectively with yield advantage of 22% (Table 3) (Elahi *et al.* (2011).

Application of parthenium water extract with lower doses of buctril super (60 EC) reduced the density and dry weight of field bindweed, fumitory (*Fumaria indica* L.), and wild onion (*Asphodelus tenuifolius* Cav.) by 55.68-83.84% and 54.65-85.96%, respectively compared with weedy check; and increased the grain yield of wheat by 51.01-90.92% than weedy check. In this regard, maximum reduction in weed density and dry weight and the highest improvement in wheat grain yield was observed when parthenium water extract (24 L ha^{-1}) was applied in combination with buctril super (60 EC; 150 ml ha^{-1}). Label rate of buctril super (750 ml ha^{-1}) reduced the weed density and dry biomass by 75.36 and 83.96% respectively over weedy check with yield advantage of 58.92%. (Table 3) (Baloach *et al.*, 20150). In another study, Razzaq *et al.* (2010) reported that combined application of sorghum and sunflower water extract with reduced doses of various herbicides (Cleaner 70 WP, Bullet 38 SC, Atlantis 12 EC, Sencor 70 WP and Atlantis 3.6 WG) in wheat reduced the density and dry weight of littleseed canarygrass and swine cress by 76.28-89.78%, and 90.41-95.63%, respectively than weedy check, and enhanced the grain yield by 20-34.29% (Table 3). The maximum improvement in wheat grain yield and the highest decrease in weed density and dry weight was observed when sorghum and sunflower water extract (each at 18 L ha^{-1}) was applied in combination with bullet 38 SC (57 g a.i. ha^{-1}). Results showed that standard dose of Cleaner 70 WP (1050 g a.i. ha^{-1}), Bullet 38 SC (190 g a.i. ha^{-1}), Atlantis 12 EC (120 g a.i. ha^{-1}), Sencor 70 WP (175 g a.i. ha^{-1}) and Atlantis 3.6 WG (14.4 g a.i. ha^{-1}) reduced the weed density and dry weight by 42.31-92.31 and 81.37-96.08% respectively over weedy check (Table 3) (Razzaq *et al.* 2010). Another study reported that sorghum+sunflower extracts combined with $1/4^{th}$ (75% less) of label rates of herbicides inhibited dry matter production of wild oat by up to 89% and canary grass by up to 92%. Lower herbicide rates+water extracts also produced wheat grain yield statistically equal with label rates of respective herbicides (Mushtaq *et al.*, 2010).

Feasibility of this option

Application of allelopathic water extracts with reduced dose of herbicides have great potential of reducing the herbicide usage. The allelopathic crops are easily available at each farmer field and farmers can easily prepare these extracts and can reduce the cost of production which is invested on herbicides. This practice is good for small scale operation and for organic culture. Moreover, the allelopathic residues have a great advantage not only for controlling weeds but also to improve chemical, physical and nutritional status of the soil, and can be applied on large scale. Indeed, plant residues affect soil pH and play significant role through improvement in soil fertility by cycling nutrients and adding organic (Kabirinejad *et al.*, 2014). For example, Prasad and Sinha (2014) reported that about 50-80% of zinc, copper and manganese taken up by wheat and rice can be recycled through residue incorporation. Moreover, certain organic acids released after residue decomposition are important for changes in soil pH and availability of micronutrients. The organic acids which are released during residue decomposition may alter the mobility and bioavailability of metals (copper and manganese) (Kabirinejad *et al.*, 2014). Crop residue retention also affects soil temperature, evapotranspiration, leaching, soil organic matter and prevent the runoff of the nutrients due to runoff (Roldan *et al.*, 2003; Shah *et al*, 2013).

Conclusion And Future Prospects

Herbicide usage in contemporary agriculture has often masked the importance of natural ways of weed management. There has been enough emphasis for the shift toward ecologically based weed management systems due to numerous reasons (Zimdhal, 2013), making sound bases for allelopathy to play significant role for weed-crop ecology (Aldrich,1984). Utilization of allelopathy for managing weeds in agro-ecosystems offers promising alternatives for sustainable weed management in this regard (Tesio *et al.*, 2010). Numerous studies carried out under diverse agro-environments and cropping systems in recent past have documented that allelopathic residues or water extracts are effective in suppressing weeds when combined with reduced doses of both pre and post emergence herbicides without any penalty on crop yields. The level of weed suppression was similar or even better when compared with the recommended dose of respective herbicides. Being predominantly a natural approach it also minimizes the negative effects associated with indiscriminate use of herbicides in contemporary agriculture. Nonetheless, it is also economically viable option. The allelopathic residues could also have a positive bearing on the soil physical, chemical and biological characteristics and thus improve the nutritional status of soil. A recent study, Khaliq *et al*. (2015) reported that total phenolics, electrical conductivity, organic carbon and nitrogen contents were increased due to the incorporation of parthenium residues with the exception of soil pH that showed a declining trend when compared with non-treated control. The soil amended with parthenium residues at 8 g kg^{-1} recorded 538%, 89%, 123%, 122% and 151% higher soluble phenolics, electrical conductivity, organic carbon, organic matter content and nitrogen content, respectively as compared with un-amended control soil. The same rate of parthenium residue incorporation decreased soil pH by 8.5% over control soil. Similar improvement in soil characteristics has also been reported due to incorporation of wheat residues in the soil (Aslam *et al*., 2015). Many of the allelochemicals released into the system also inhibit nitrification in the rhizosphere, and conserve both the nitrogen and energy in the agro-ecosystems. Moreover, this approach has a great potential in reducing the herbicide input in ecosystem and decreasing the chance of developing resistance. The presence of a variety of allelochemicals in the decomposing crop/plant residues and aqueous extracts exposes the weeds to be vulnerable to different modes of action, and hence likely to avert the development of herbicide resistance [36]. Using herbicide mixtures instead of any single herbicide has also been suggested as a means of minimizing the chances of development of resistance in weeds. Continuous use of heavy doses of herbicides exert high selection pressure which accelerates the development of herbicide resistance. Combined application of crop residues and water extracts with reduced doses of herbicides offers promising results where such selection pressure rarely lead to evolution of herbicide resistant weed biotypes (Jasieniuk *et al*, 1996; Reznick and Cameron, 2001). Besides controlling weeds, the allelopathic residues alone or in combination with the lower dose of the test herbicide enhances sporulation and growth of mycorrhiza and reduce the loss of nitrogen through nitrification inhibition in soil.

Future studies may include evaluating the synergetic effects of allelopathic water extracts and herbicides when they are blended together for weed management purposes. Besides controlling weeds, the allelopathic mulches of rice, sorghum and brassica has the ability to reduce the loss of nitrogen through nitrification inhibition, which needs comprehensive evaluation under varying agro-environments. Influence of allelochemicals released from the crop residues or through root exudation on soil nitrification and mycorrhizal formation and their corresponding consequences on rhizosphere ecology needs lot of attention for sustainability of the system.

Table 1 : Effect of half label dose of trifuraline herbicide in combination with different rates of sunflower residues cv. Coupan on total weed number and dry biomass and seed yield of broad bean.

Herbicide rates (% of label rate)*	**Residue rates (g/m^2)****			
	0	**600**	**1400**	**Average**
Total weed number per m^2				
0% (Control)	378.5	244.5	537.5	1180.3
50%	184.0	133.5	323.0	452.3
75%	146.5	117.0	230.5	357.2
100%	127.0	96.5	148.0	258.0
Average	209.0	147.9	309.8	
LSD ≤ 0.05	H =11.17	R = 10.50	H×R =78.9	
Total dry weed biomass ($g\ m^{-2}$)				
0% (Control)	1877.0	1126.5	537.5	1180.3
50%	618.5	415.5	323.0	452.3
75%	497.0	344.0	230.5	357.2
100%	359.0	267.0	148.0	258.0
Average	837.9	538.3	309.8	
LSD ≤ 0.05	H =49.1	R = 35.9	H×R =78.9	
Seed yield ($g\ m^{-2}$)				
0% (Control)	282.75	466.00	576.50	441.75
50%	638.75	706.00	700.70	681.82
75%	643.75	767.50	910.00	773.75
100%	671.25	853.25	1045.00	856.50
Average	559.12	698.18	808.05	
LSD ≤ 0.05	H = 63.8	R = 88.5	H×R =121.3	H×R =121.3

[*] Trifluralin applied at 2.4 L ha^{-1}. [**] Each value is an average of 4 replicates

Table 2 : Effect of half label dose of trifuraline herbicide in combination with different rates of sorghum residues on weeds and yield of broad bean

Treatments	2010			2011		
	Weed density (plants m^{-2})	Weed biomass ($g\ m^{-2}$)	Seed yield ($t\ ha^{-1}$)	Weed density (plants m^{-2})	Weed biomass ($g\ m^{-2}$)	Seed yield ($t\ ha^{-1}$)
Weedy check	317.3	1013.2	0.72	158.7	362.4	3.15
Residues at 3.50 t ha^{-1}	170.7	622.4	1.04	62.7	236.9	5.08
Residues at 5.3 t ha^{-1}	124.0	546.0	1.63	54.7	170.2	4.89
Residues at 7.6 t ha^{-1}	124.0	500.8	1.52	44.0	112.3	5.33
Residues at 3.5 t ha^{-1} +50% of dose of trifluralin	114.7	585.6	1.55	53.3	167.0	5.49
Residues at 5.3 t ha^{-1} +50% of dose of trifluralin	125.3	498.8	1.69	39.3	140.5	5.30
Residues at 7.6 t ha^{-1}+50% of dose of trifluralin	85.3	305.6	2.06	21.7	97.4	5.67
Trifluralin (Label dose)	104.0	720.0	1.70	71.3	**225.9**	5.19
Weed free	34.1	169.7	0.36	27.7	36.3	6.97
LSD value ($p \leq 0.05$)	34.1	169.7	0.36	27.7	36.3	0.65

Table 3: Weed control in wheat through combination of allelopathic water extracts and reduced doses of herbicides.

Allelopathic extract + herbicide dose	Major weeds controlled	Reduction (%)						Reference
		Water extracts + herbicide			Herbicide alone*			
		Density	Dry weight	Yield** (%)	Density	Dry weight	Yield** (%)	
		83.33	77.94	20.00	90.19	85.71	17.64	Razzaq *et al.*, 2012
Sorghum WE (18 L ha^{-1}) + sunflower WE (18 L ha^{-1}) + Bensulfuron + isoproturon (Cleaner 70 WP) @ 315 g a.i. ha^{-1}	Swine cress, littleseed canarygrass	88.24	88.45	23.81	81.37	85.71	15.24	Razzaq *et al.*, 2012
Sorghum WE (18 L ha^{-1}) + sunflower WE (18 L ha^{-1}) + Metribuzin + phenoxaprop (Bullet 38 SC) @ 57 g a.s. ha^{-1}	Swine cress, littleseed canarygrass	87.25	91.60	34.29	87.25	85.71	17.14	Razzaq *et al.*, 2012
Sorghum WE (18 L ha^{-1}) + sunflower WE (18 L ha^{-1}) + Mesosulfuron + idosulfuron (Atlantis 12 EC) @ 36 g a.i. ha^{-1}	Swine cress, littleseed canarygrass	87.25	92.86	21.90	90.60	86.13	13.33	Razzaq *et al.*, 2012
Sorghum WE (18 L ha^{-1}) + sunflower WE (18 L ha^{-1}) + Mesosulfuron + idosulfuron (Atlantis 3.6 WG) @ 4.32 g a.i. ha^{-1}	Swine cress, littleseed canarygrass	87.25	90.34	20.48	96.08	93.49	24.76	Razzaq *et al.*, 2012
Rice extract (500 kg ha^{-1}) + Puma Super 750EW (625 ml ha^{-1})	-	57.62	-	-	32.09	-	-	Afridi and Khan, 2014
Rice extract (500 kg ha^{-1}) + Buctril Super 600EC (375 ml ha^{-1})	-	56.36	-	-	28.53	-	-	Afridi and Khan, 2014
Parthenium hysterophorus L. (500 kg ha^{-1}) + Puma Super 750EW (625 ml ha^{-1})	-	75.94	-	-	-	-	-	Afridi and Khan, 2014
Parthenium hysterophorus L. (500 kg ha^{-1}) + Buctril Super 600EC (375 ml ha^{-1})	-	75.66	-	-	-	-	-	Afridi and Khan, 2014
Phragmites australis Cav. extract (500 kg ha^{-1}) + Puma Super 750EW (625 ml ha^{-1})	-	64.62	-	-	-	-	-	Afridi and Khan, 2014
Phragmites australis Cav. extract (500 kg ha^{-1}) + Buctril Super 600EC (375 ml ha^{-1})	-	62.52	-	-	-	-	-	Afridi and Khan, 2014
Datura alba L. extract (500 kg ha^{-1}) + Puma Super 750EW (625 ml ha^{-1})	-	70.91	-	-	-	-	-	Afridi and Khan, 2014
Datura alba L. extract (500 kg ha^{-1}) + Buctril Super 600EC (375 ml ha^{-1})	-	69.37	-	-	-	-	-	Afridi and Khan, 2014
Sorgaab conc. @ 6 L ha^{-1} + Isoproturon @ 150 g a. i. ha^{-1}	-	53.00	42.10	27.31	91.67	94.05	64.13	Jamil *et al.*, 2005
Sorgaab conc. @ 6 L ha^{-1} + Isoproturon @ 300 g a. i. ha^{-1}	-	59.78	53.83	39.81	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 6 L ha^{-1} + Isoproturon @ 450 g a. i. ha^{-1}	-	78.86	71.53	41.70	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 6 L ha^{-1} + Isoproturon @ 600 g a. i. ha^{-1}	-	87.07	82.03	57.20	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 12 L ha^{-1} + Isoproturon @ 150 g a. i. ha^{-1}	-	60.88	57.08	30.13	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 12 L ha^{-1} + Isoproturon @ 3000 g a. i. ha^{-1}	-	78.23	76.23	48.36	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 12 L ha^{-1} + Isoproturon @ 450 g a. i. ha^{-1}	-	86.75	85.88	64.68	-	-	-	Jamil *et al.*, 2005
Sorgaab conc. @ 12 L ha^{-1} + Isoproturon @ 600 g a. i. ha^{-1}	-	91.17	93.04	79.18	-	-	-	Jamil *et al.*, 2005
Sorgaab @ 12 L ha^{-1} + Mesosulfuron methyl (Atlantis 3WG) 6.25 g a.i. ha^{-1}	Wild oat, purple nutsedge, lambsquarter	**75.89**	**79.28**	18.65	84.75	86.48	19.47	Sharif *et al.*, 2005
Sorgaab @ 12 L ha^{-1} + Bromoxinil + MCPA (Buctril super 60EC) @ 215 g a.i.ha^{-1}	Wild oat, purple nutsedge, lambsquarter	**74.23**	**11.94**	8.02	76.44	75.00	10.86	Sharif *et al.*, 2005

Sorgaab @ 12 L ha^{-1} + Isopruturon (Tolkan 50W) @ 500 g a.i.ha^{-1}	Wild oat, purple nutsedge , lambsquarter	**80.60**	**76.42**	17.77	78.66	70.95	17.54	Sharif *et al.*, 2005
Sorgaab @ 12 L ha^{-1} + Bromoxinil + MCPA (Buctril M 40EC) 250 g a.i. ha^{-1}	Wild oat, purple nutsedge, lambsquarter	**60.93**	**16.67**	5.17	72.01	47.30	9.44	Sharif *et al.*, 2005
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Mulberry WE (18 L ha^{-1}) + Atlantis 3.6 WG (7.20 g a.i. ha^{-1})	Littleseed canarygrass, wild oat, lambsquarter, black clover	**85.72**	**88.16**	36.15	81	84	31	Mahmood *et al.*, 2013
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Mulberry WE (18 L ha^{-1}) + Atlantis 3.6 WG (4.80 g a.i. ha^{-1})	Littleseed canarygrass, wild oat, lambsquarter, black clover	**66.82**	**74.57**	19.25	-	-	-	Mahmood *et al.*, 2013
Sorgaab WE (15 L ha^{-1}) + Brassica WE (15 L ha^{-1}) + Sunflower WE (15 L ha^{-1}) + Bromoxynil + MCPA (33 g a.i. ha^{-1})	Field bindweed, sun spurge, white-flowered sweet clover	**80.63**	**94.31**	7.69	78.57	96.37	7.14	Iqbal *et al.*, 2010
Sorghum WE (12 L ha^{-1}) + Brassica WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + phenoxaprop-p-ethyl (287 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**12.16**	**39.16**	10.29	26.20	63.05	22.38	Elahi *et al.*, 2011
Sorghum WE (12 L ha^{-1}) + Brassica WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + Isoproturon (333 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**94.43**	**98.79**	16.15				Elahi *et al.*, 2011
Sorghum WE (12 L ha^{-1}) + Brassica WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + phenoxaprop-p-ethyl (287 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**21.03**	**72.69**	13.00	-	-	-	Elahi *et al.*, 2011
Sorghum WE (12 L ha^{-1}) + Brassica WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + Isoproturon (333 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**96.55**	**97.79**	19.24	98.94	97.59	30.21	Elahi *et al.*, 2011
Sorghum WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + phenoxaprop-p-ethyl (287 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**58.20**	**85.54**	15.35	-	-	-	Elahi *et al.*, 2011
Sorghum WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + Isoproturon (333 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**96.04**	**96.38**	22.79	-	-	-	Elahi *et al.*, 2011
Brassica WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + phenoxaprop-p-ethyl (287 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**33.59**	**69.68**	12.88	-	-	-	Elahi *et al.*, 2011
Brassica WE (12 L ha^{-1}) + Sunflower WE (12 L ha^{-1}) + Rice WE (12 L ha^{-1}) + Isoproturon (333 g a.i. ha^{-1})	Swine cress, sour clover (*Melilotus parviflora* Desf.)	**95.77**	**96.18**	20.01	-	-	-	Elahi *et al.*, 2011
Parthenium WE (24 L ha^{-1}) + Buctril Super 60 EC @ 300 ml ha^{-1}	Field bindweed, fumitory, wild onion	**55.68**	**70.55**	51.01	75.36	83.96	58.92	Baloach *et al.*, 2014
ienium WE (24 L ha^{-1})+ Buctril Super 60 EC @ 225 ml ha^{-1}	Field bindweed, fumitory, wild onion	**60.16**	**54.65**	68.07	-	-	-	Baloach *et al.*, 2014
Parthenium WE (24 L ha^{-1}) + Buctril Super 60 EC @ 150 ml ha^{-1}	Field bindweed, fumitory, wild onion	**83.84**	**85.96**	90.92	-	-	-	Baloach *et al.*, 2014
Parthenium WE (24 L ha^{-1}) + Buctril Super 60 EC @ 75 ml ha^{-1}	Field bindweed, fumitory, wild onion	**76.64**	**84.47**	75.79	-	-	-	Baloach *et al.*, 2014
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Sencor 70 WP (52.5 g a.i. ha^{-1})	Littleseed canarygrass, swine cress	76.28	90.41	20.00	92.31	90.6	-	Razzaq *et al.*, 2010
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Cleaner 70 WP (315 g a.i. ha^{-1})	Littleseed canarygrass, swine cress	88.35	91.02	23.81	84.62	81.37	-	Razzaq *et al.*, 2010
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Bullet 38 SC (57 g a.i. ha^{-1})	Littleseed canarygrass, swine cress	89.78	95.63	34.29	88.46	87.25	-	Razzaq *et al.*, 2010
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Atlantis 12 EC (36 g a.i. ha^{-1})	Littleseed canarygrass, swine cress	87.86	95.41	21.90	42.31	90.6	-	Razzaq *et al.*, 2010
Sorghum WE (18 L ha^{-1}) + Sunflower WE (18 L ha^{-1}) + Atlantis 3.6 WG (4.32 g a.i. ha^{-1})	Littleseed canarygrass, swine cress	87.86	92.87	20.48	92.31	96.08	-	Razzaq *et al.*, 2010

*= recommended dose of herbicide; **= percent yield increase over control (weedy check)

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