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Original article

Integrated Management of Alligatorweed in Autumn Planted Sunflower

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Abstract

The persistent and proliferating growth habit of alligatorweed makes this weed difficult to control in crops. Therefore, its integrated control by employing pre- and post-emergence herbicides along with cultural weed control methods may be required for its long-term sustained management in sunflower crop. Two-years field investigation was therefore conducted to compare the efficacy of different weed management strategies (plastic sheet mulch, pre-emergence application (PEA) of S-metolachlor, PEA of S-metolachlor + alligatorweed mulch 40 days after sowing (DAS), PEA of S-metolachlor + directed post-emergence application (DPOEA) of glufosinate 20 DAS, single and dual DPOEA of glufosinate with or without adjuvants (alkyl ether sulphate / ammonium sulphate) for controlling alligatorweed in autumn planted sunflower. All weed management treatments reduced alligatorweed growth, its nutrients' uptake and thus enhanced sunflower growth and yield. Plastic sheet mulch gave 100% control of alligatorweed. However, among herbicide treatments, PEA of S-metolachlor + DPOEA of glufosinate caused the highest reductions in alligatorweed density (95%), its dry biomass (98%), its macronutrients' (up to 98%) and micronutrients' (up to 99%) uptakes over weedy check. Maximum sunflower achene yield increase was recorded with plastic sheet mulch (124%) followed by PEA of S-metolachlor + DPOEA of glufosinate (84%). The economic analysis revealed that PEA of S-metolachlor + DPOEA of glufosinate 20 DAS gained the higher net benefit (US$138 and US$157) as well as benefit-cost ratio (6.87 and 6.36) during years 2015 and 2016, respectively. Therefore, in terms of better alligatorweed control, sunflower yield and cost-effectiveness, PEA of S-metolachlor + DPOEA of glufosinate 20 DAS could be considered the best option recommended for sunflower growers.

Keywords: Achene Yield, Alligatorweed, Herbicides, Plastic Mulch, Nutrients Uptake, Sunflower

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INTRODUCTION

Use of herbicides to control weeds is an economical, time saving and proficient technique which can give 42-97% higher crop yields as compared to the unchecked weed growth (Simic et al. 2011). Pre-emergence herbicides are considered more effective and reliable for controlling weeds in sunflower. S-metolachlor is the most commonly used pre-emergence herbicide of sunflower (Reddy et al. 2012). It is an α-chloroacetamide that inhibits the production of long chain fatty acids in the susceptible plants (Böger, 2003). Glufosinate, a phosphinic acid, is a non-selective foliar applied broad-spectrum herbicide which blocks the activity of glutamine synthetase (GS), an enzyme which synthesizes glutamine by utilizing glutamate and ammonium (Obojska et al., 2004; Green and Owen, 2011). It has no soil residual activity. It is a post-emergence non-selective herbicide has been known to give effective control of glyphosate resistant weeds (Cahoon et al., 2015). So, there stands an option to use glufosinate to control the weeds that escape from pre emergence herbicides. Although weed control through herbicides is most common practice among growers, these do not give 100% control of weeds (Reddy et al., 2015). Moreover, sole reliance on herbicides is neither sustainable nor safer for abiotic and biotic components of agroecosystem (Ruuskanen et al., 2023). Suryavanshi et al. (2015) noted that integrated use of pre- and post-emergence herbicides gave broad spectrum weed control in sunflower. To make a weed management program more integrated, other weed control options such as plastic or organic mulching should also be employed along with herbicides. Plastic mulches have been known to give 84 to 100% control of the weeds in tomato and corn (Rajablariani and Sheykhmohamady, 2015). In addition to weed control, plastic mulching gives better conservation of water, thus ultimately increasing crop yields (Ingman et al., 2015). Growers must understand the importance of integrated weed control and using new and improved technologies in combination with the older ones for sustainable and economical weed control (Green, 2014).

Due to unavailability of its herbicide-resistant genotypes in Pakistan, weed control in sunflower is not much easier. Autumn planted sunflower crop is infested by a number of broadleaf weeds, grasses and sedges. However, the most problematic of these are purple nutsedge (*Cyperus rotundus* Linn.), sweet signalgrass [*Brachiaria eruciformis* (Sm.) Griseb.], Egyptian grass [*Dactyloctenium aegyptium* (L.) Willd,] desert horsepurslane (*Trianthema portulacastrum* L.), false daisy [*Eclipta prostrata* (L.) L.], pillpod sandmat (*Euphorbia hirta* L.), least snoutbean [*Rhynchosia minima* (L.) DC.] and cantaloupe (*Cucumis melo* L.) (Qureshi and Memon 2008). In addition, some new invasive weeds are also becoming prevalent and are a greatest hazard to natural biodiversity of ecosystems throughout the world (Levine et al., 2003). Among the invasive weeds, *Alternanthera philoxeroides* (Mart.) Griseb. commonly called alligatorweed is a highly competitive allelopathic invasive weed. This weed belongs to family *Amaranthaceae*. Its indigenous place is South America but is now colonizing in all parts of the world (Sosa et al., 2008). It is considered to be a troublesome invasive weed in almost 30 countries including United States of America, China, Australia, New Zealand, Indonesia, Puerto Rico, Thailand, India and Pakistan (USDA-ARS, 2016).

In the middle of 20th century, alligatorweed came in Indo-Pak and now has colonized in the entire subcontinent (Masoodi et al., 2013). It is an invasive dangerous weed disturbing the global biodiversity and ecosystem functionality (Bassett et al., 2012). Alligatorweed has the potential to disturb any cropping system of the world (Oosterhout, 2007). It has badly invaded wetlands of Pakistan (Shabbir et al., 2018). As Pakistani agro-ecological conditions are suitable for its growth, it is spreading furiously. It can grow alone as well as in competition with many crops resulting in drastic yield losses of up to 60% in vegetables, rice, soybean, maize, fruit trees and cotton (Ye et al., 2003; Tanveer et al., 2013; Mehmood et al., 2018; Nadeem et al., 2018).

Alligatorweed has also been proved to be allelopathic against germination and growth of rice, lettuce and maize (Mehmood et al., 2014; Kleinowski et al., 2016; Nadeem et al., 2017). Its chemical control is considered most feasible than physical methods that in fact encourage its spread. This is because its robust propagation occurs through fragmentation i.e. each node after its burial develops into a new plant (Sainty et al., 1998). Therefore, long-term herbicidal application along with physical means to check emerging above-ground plant parts and to exhaust underground storage organs is required for its effective control (Van Oosterhout, 2007). Limited information is available regarding herbicides for its sustained management. However, a very few herbicides such as glyphosate, 2, 4-D, metsulfuron methyl, carfentrazone and glufosinate as their post-emergence application give good control (Bhalla et al., 2022). A complete control through herbicides is somewhat difficult to attain as most of the herbicides kill top portion of plant without affecting older stems and rhizomes (Schooler et al., 2008). Keeping in view the widespread proliferation and huge yield losses of alligatorweed in crops, its effective control in field crops is needed to discover. In this regard, integrated use of pre- and post-emergence herbicide with tank-mixture with adjuvants accompanied by cultural methods might be an effective strategy for management of this weed. Therefore, studies were planned with the objective to compare the efficacy of different integrated weed control measures for managing alligatorweed in sunflower.

MATERIALS AND METHODS

Study site: Field studies for two consecutive autumn seasons of years 2015 and 2016 were performed at the research area of University of Agriculture, Faisalabad, Pakistan. The experimental site was located at 31.25^{o}N latitude, 73.09^{o}E longitude and 184.4 m altitude. The soil was sandy clay loam with 7.8 pH, 0.06 % N, 212 ppm available K, 0.65% organic matter, and 7.1 ppm available P. The 19 to 31^{o}C and 20 to 31^{o}C mean monthly temperatures, and 146 and 82 mm total monthly rainfalls prevailed during growing seasons of years 2015 and 2016, respectively (data not shown).

Experimentation and growing conditions: Treatments studied were enlisted in Table 1. Pre-emergence herbicide application was done just after crop sowing while post-emergence herbicide was applied 20 days after sowing (DAS). In case of post-emergence application twice, first spray was carried out 20 DAS whereas second spray 40 DAS. The Na salt of AES was used. Hand-operated Knapsack sprayer was used for spraying herbicides. Before herbicide application, spray machine was calibrated with water to know exact volume (316 L ha^{-1}) of water. Randomized complete block design was used as layout design with four replications of each treatment. Net plot size of 9.2 m × 6 m was maintained.

Sunflower hybrid Hysun-33 was sown on 8 August, 2015 and 23 August, 2016 on 75 cm spaced ridges with 22.5 cm plant-to-plant distance. Seed rate was 5 kg ha^{-1}. The field was selected where profound infestation of alligatorweed was observed previously. Before sowing, irrigation was applied to furrows between ridges and seed was sown on one side of ridges manually just above water line. In mulching treatments, mulches were spread over ridges but not in furrows. Nitrogen (N), phosphorus (P) and potash (K) were applied at 150, 100 and 62 kg ha^{-1}, respectively. Urea was used as N, DAP (diammonium phosphate) as P while sulphate of potash (SOP) as K source. Whole of the P and K besides 1/5th N dose were broadcasted and mixed in soil at the time of sowing. Remaining amount of N was equally applied with 1st irrigation (15 days after crop emergence), 2nd irrigation (30 days after crop emergence) and at flowering (60 days after crop emergence). Five irrigations each with an interval of 15 days were applied. Each irrigation was of 3 acre inches. In all plots (treatments), only alligator weed was allowed to grow whereas all other weeds were uprooted manually soon after emergence. In weedy check, no alligatorweed seedling was removed throughout the growing season of sunflower.

Data recorded: Data of sunflower crop i.e. plant population per hectare, head diameter (cm), achenes' count and weight per head (g), 1000-achene weight (g), achene yield (kg ha^{-1}), achene oil content (%) (Low, 1990), oil yield (kg ha^{-1}) were recorded near crop maturity and at harvest. Five plants / heads per plot were selected at random to estimate plant height, head diameter and per head achene count while plants from whole plot were harvested to get achene and oil yield. Alligator weed population per m^2, dry weight (g m^{-2}), NPK uptake (kg ha^{-1}) (Williams 1984), micronutrients uptake (kg ha^{-1}) (Jones et al. 1991), weed control efficiency (%), relative competitive index (%) were recorded following their standard procedures.

Statistical and economic analysis: Fisher's analysis of variance procedure was used for statistical analysis of data and Tukey's honestly significant difference test was used for treatment means' comparison at 5% p value (Steel et al. 1997. If a parameter showed non-significant variations over the year of study, than mean values for both the years were presented and discussed. Contrast analysis between different treatment groups was carried out made by employing single degree of freedom (df) method (Little and Hills 1978). The economic analysis was also performed.

RESULTS AND DISCUSSION

Alligatorweed density and dry weight: Table 2 illustrates that density and dry weight of alligatorweed was significantly lowered in response to different integrated weed management techniques over weedy check. No alligatorweed germinated where black plastic sheet was used as mulch. Pre-emergence application (PEA) of S-metolachlor along with directed post-emergence application (DPOEA) of glufosinate or alligator weed mulch (AWM) gave more effective control of alligatorweed as these treatments caused the highest reduction (90-95%) in alligatorweed density. Minimum dry weight of alligatorweed was noted with PEA of S-metolachlor + DPOEA of glufosinate. However, these treatments did not differ significantly from all the treatments apart from weedy check and DPOEA of glufosinate. Contrast comparison of different treatments (Table 3) showed that treatments with PEA performed better than those having post-emergence herbicides. Moreover, double post-emergence herbicide application performed better than its single application in terms of controlling alligator weed. Further, it can be inferred that addition of adjuvants in glufosinate reduced its efficacy.

Significant decrease in alligatorweed density and dry weight recorded at harvest for all treatments depicted that alligator weed control in one or the other way was better than weedy check (control). Baskaran and Kavimani (2014) reported similar results while carrying out weed control trials in sunflower. They recorded lowest density of weeds when they combined pre-emergence pendimethalin application with tillage + hoeing 40 days after sowing. Findings of Balasubramanian et al. (2001) are in great coordination to the results of this experiment. They reported that application of herbicides results in significant decrease in the density of weeds. They concluded that maximum weed control efficiency (96.58% and 97.04%) was recorded with fluchloralin at 1.5 kg a.i ha^{-1} when it was combined with one hand weeding 30 days after sowing. Not only this treatment was helpful in controlling weed density in summer season but also helped in managing the weed biomass in upcoming winter season.

Weed control efficiency (%): Comparison of weed control efficiencies (WCEs) of different weed control treatments are presented in Figure 1. Figure reveals that different weed control treatments resulted in different WCE for allligatorweed ranging from 71 to 100%. In 2015, Maximum WCE (100%) was recorded in treatment where plastic sheet was used as mulch. This was followed by those of PEA of S-metolachlor + DPOEA of glufosinate 20 DAS, PEA of S-metolachlor + AWM and PEA of S-metolachlor with 98, 95 and 95 % WCE. Minimum WCE (71%) among the treated plots was recorded with DPOEA of glufosinate 20 DAS. Maximum WCE of plastic sheet was probably due to its prohibitive effect of light as light is necessary for growth of any type of plant. The highest weed control efficiency of PEA of S-metolachlor + DPOEA of glufosinate was observed because these herbicides didn't allow alligatorweed to sprout and grow. Renukaswamy et al. (2012) conducted an experiment and found out that alachlor (1.0 l ha^{-1}) combined with metolachlor (0.75 l ha^{-1}) as PE gave maximum weed control efficiency with minimum weed denisty and biomass as compared to other herbicidal treatments.

Alligatorweed nutrients' uptake: All weed control treatments resulted in significant decline in alligatorweed macronutrients (N, P, and K) and micronutrients (Fe, Mn, Zn and Cu) uptakes. Among treatments, the highest reduction (up to 99%) of N, P, K, Fe, Mn, Zn, Cu uptakes by alligatorweed were noted with PEA of S-metolachlor + DPOEA of glufosinate 20 DAS. Contrast comparison of different treatments (Table 3) showed that reduced uptake of nutrients by alligator weed occurred within plots treated with pre-emergence herbicide application as compared to those having post-emergence herbicides. Similarly, double post-emergence herbicide application remained better as compared to single application. Further, addition of adjuvants in glufosinate reduced its efficacy.

Crops are usually poor competitor than weeds and cannot out-compete weeds when grown together. In this study, the highest nutrients' uptake by alligatorweed was recorded in weedy check plots apparently due to its luxurious growth as evinced by higher dry weight. However, keeping check on its growth in the plots where weed management techniques were applied resulted in decreased biomass and nutrients' uptake.

Present findings agree with those of Satyareddi et al., (2015). They concluded that ineffective weed treatments accounted for higher nutrients in weeds. Un-weeded control accounted for significantly higher NPK in weeds on account of profound competition of sunflower with weeds. Lehoczky et al. (2006) concluded that crop growth is negatively affected when deprived of nutrients up taken by weeds in its earlier growing season. The result was 22% less N, 31% less P and 43% less K in shoots of weed-infested sunflower as compared to weed-free sunflower. Increased *R. capitata* competition with mungbean resulted in more uptake of nutrients by the weed when its growth was unchecked (Ali et al. 2015). Madhu et al. (2006) revealed that unchecked growth of weed results in depletion of 72.31 kg N, 19.00 kg P_2O_5 and 30.39 kg K_2O per hectare. Weed free check recorded significantly higher nutrient uptake by crops than all other treatments but was on par with the treatments which received application of herbicides combined with one inter-cultivation and one hand weeding.

Siddiqui et al. (2009) reported that if weed free conditions are maintained throughout the sunflower growth period, use of micro-nutrients by the sunflower crop increases to a great extent. Babaeian et al. (2011) concluded that if weed are controlled by hand weeding, maximum amount of Zn, Cu and Fe is accumulated in sunflower achenes. Biware et al. (2013) stated similar results when they compared an invasive weed *Alternanthera* sp. with a native weed *Euphorbia* sp. for its uptake of micro-nutrients. *Alternanthera* absorbed excessive amount of nutrients in comparison to *Euphorbia* resulting in excessive growth of *Alternanthera* over the surface of water forming monothickets.

Sunflower achene yield and underlying traits: Table 4 presented the data regarding sunflower achene yield and underlying traits which depicts maximum head diameter, achenes' count per head, per head achene weight and achene yield of sunflower in plots covered with plastic sheet mulch during year 2015 and 2016, respectively. While this treatment also showed the highest 1000-achene weight as shown by two-year mean data. However, among herbicide treatments, PEA of S-metolachlor + DPOEA of glufosinate could be ranked the most superior as it gave the highest head diameter (17.36 and 18.87 cm), achenes' count per head (962.8 and 1000.4), per achene weight (45.86 and 47.64 g) and achene yield (2672.2 and 2755.0 kg ha^{-1}) of sunflower during the year 2015 and 2016, respectively. While this treatment also showed the highest 1000-achene weight (47.26 g) as shown by two-years mean data. The PEA of S-metolachlor + AWM 40 DAS also gave statistically similar values of head diameter and achenes per head whereas the second highest values of achene weight per head, 1000-achene weight and achene yield of sunflower in years 2015 and 2016, respectively. On the other hand, the lowest values of all these parameters were noted with weedy plots without any weed control. It is worth-mentioning that under fully uncontrolled weedy conditions by alligator weed, achene yield loses went up to a 55%. Contrasts comparisons (Table 5) showed that all weed control treatments significantly increased the sunflower achene yield and its underlying traits. Further, plastic sheet mulching was proved to be the best than all weed control treatments. Similarly, pre-emergence herbicide treatments remained better than post-emergence herbicide treatments while dual post-emergence spray gave good results than single one. Moreover, addition of adjuvants to glufosinate made no improvement in sunflower achene yield and underlying traits.

Increase in achene yield and yield contributing traits shown by weed control treatments was attributed to reduced alligatorweed competition as depicted by its lowered dry weight in those treatments than observed in untreated control. The plots where alligatorweed was not controlled, its aggressively growing plants deprived sunflower crop of basic growth factors by up-taking nutrients and water thus reducing its growth. Previous researchers also found betterment in sunflower growth, yield and yield attributes by integrated weed management. Shah et al. (2016) recorded enhancement in sunflower achene yield, head diameter, per head achene count and achene weight, 1000-achene weight by applying pre-emergence application of 33% dose of S-metolachlor + sorghum aqueous extracts due to better weed control. Achene yield, diameter of capitulum, per capitulum achenes' count of sunflower increased significantly when hand weeding was done twice in the growing season of sunflower, 1st at 15 DAS and 2nd at 30 DAS. However it was at par to the management plan in which fluchloralin was applied at 1.5 kg a.i ha^{-1} accompanied by intercropping with black gram (Shylaja and Sundari 2008). Saudy and El-metwally (2009) reported that weed management techniques can affect the yield and yield characteristics of sunflower significantly. Butralin + prometryn application resulted in increment of seed weight/plant, amounted by 50%. Moreover, hand weeding was regarded as best tool for increasing seed index exceeding the unweeded by 14%. Pannacci et al. (2007) concluded that pre-emergence application of S-metolachlor in mixture with aclonifen and oxyfluorfen gave good weed control along with the highest achene yield. Singh and Singh (2006) demonstrated that 1000-seed weight of sunflower increased significantly with the pre-emergent pendimethalin spray at 1 kg a.i ha^{-1}.

Oil content and oil yield of sunflower: Oil yield is ultimate goal of growing sunflower crop. Treatments did not differ significantly with respect to achene oil content that ranged from 30% to 40% (Data not shown). Table 4 showed that among different weed control treatments, mulching with plastic sheet produced significantly the peak oil yield of sunflower. However, among herbicide treatments, significantly the highest oil yield of sunflower was recorded with PEA of S-metolachlor + DPOEA of glufosinate 20 DAS. This treatment was followed by PEA of S-metolachlor @ + AWM at 40 DAS as it attained the second highest values of sunflower oil yield. Minimum oil yield was recorded with weedy check. Contrasts regarding oil yield exhibited that for getting higher oil yield of sunflower, pre-emergence herbicide treatments remained better than post-emergence herbicide treatments while dual post-emergence spray gave good results than single one, and no difference was recorded in the glufosinate with adjuvant vs without adjuvant (Table 5). The increase in oil yield of sunflower due to weed control treatments was the result of its increased achene yield due to less weed competition as sunflower oil content were statistically same among different treatments. Jayakumar et al. (1988) also noted that sunflower oil yield was reduced to 336 kg ha^{-1} in the unweeded control in comparison to that recorded with weed control treatments.

Economic analysis: The comparison of different alligatorweed control treatments regarding their net returns and cost-benefit ratios for the years 2015 and 2016 have been given Tables 6 and 7, respectively. It is obvious from the data that un-controlled alligatorweedy conditions resulted in negative net benefits (US$-32 and US$-18) in the years 2015 and 2016, respectively. It means that if this weed is not controlled in sunflower, farmer will have to face loss instead of profit. This loss could be converted into benefit by controlling this weed. Among weed control treatments, plastic sheet mulching attained the highest net benefit of US$156 and US$177 in year 2025 and 2016, respectively. This treatment was followed by S-metolachlor + DPOEA of glufosinate 20 DAS regarding net benefit. However, in terms of benefit cost ratio (BCR), PEA of S-metolachlor and S-metolachlor + DPOEA of glufosinate 20 DAS remained at first and second positions as these attained higher BCRs in years 205 (8.56 and 6.87) and 2016 (7.18 and 6.36), respectively. Regarding the overall economic benefit, S-metolachlor + DPOEA of glufosinate 20 DAS could therefore be considered the most cost-effective treatment as it gained the higher net return as well as BCR.

CONCLUSION

It can be inferred from the study that pre-emergence application of S-metolachlor followed by directed post-emergence application of glufosinate 20 DAS is the most effective, feasible and economical alligatorweed control option in autumn planted sunflower.

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Table 1**.** List of treatments studied.

Sr. No.	Treatment code	Treatment
1	T_1	Control (weedy check)
2	T_2	plastic-sheet mulching
3	T_3	S-metolachlor pre-emergence application (PEA) at 1896 g a.i. ha^{-1}
4	T_4	PEA of S-metolachlor + alligatorweed weed mulch (AWM) at 5 t ha^{-1} at 40 days after sowing (DAS)
5	T_5	PEA of S-metolachlor + directed post-emergence application (DPOEA) of glufosinate @ 600 g a.i. ha^{-1} 20 DAS
6	T_6	DPOEA of glufosinate at 600 g a.i. ha^{-1} 20 DAS
7	T_7	DPOEA of glufosinate + alkyl ether sulphate (AES) Na salt @ 400 ml ha^{-1} at 20 DAS
8	T_8	DPOEA of glufosinate, 1st at 20 DAS, 2nd at 40 DAS
9	T_9	DPOEA of glufosinate + AES Na salt @ 400 ml ha^{-1} 1st at 20 DAS, 2nd at 40 DAS
10	T_{10}	DPOEA of glufosinate + 2 % ammonium sulphate (AMS) at 20 DAS
11	T_{11}	DPOEA of glufosinate + 2 % AMS, 1st at 20 DAS, 2nd at 40 DAS

Table 2. Alligator weed growth traits under the influence of different weed control treatments.

Treatments	Weed density (plants m^{-2})	Weed dry biomass (g m^{-2})	N-uptake (kg ha^{-1})	P-uptake (kg ha^{-1})	K-uptake (kg ha^{-1})	Fe-uptake (g m^{-2})	Mn-uptake (g m^{-2})	Zn-uptake (g m^{-2})	Cu-uptake (g m^{-2})	
	Two-year means								2015	2016
T_1	209.04 a	198.15 a	57.07 a	43.80 a	51.57 a	198.98 a	128.78 a	67.56 a	19.14 a	16.41 a
T_2	----	----	-----	----	-----	----	----	----	----	----
T_3	26.15 de	9.44 c	2.17 c	1.65 c	1.69 c	4.54 c	3.31 c	1.92 c	0.74 c	0.50 c
T_4	19.04 ef	9.57 c	2.13 c	1.62 c	1.66 c	4.09 c	3.34 c	1.76 c	0.74 c	0.50 c
T_5	8.63 f (95%)*	3.82 c (98%)	0.70 c (98%)	0.55 c	0.57 c	1.39 c	1.26 c (99%)	0.65 c	0.28 c	0.19 c
T_6	94.33 b	55.89 b	13.89 b	10.09 b	13.16 b	42.24 b	29.74 b	15.70 b	4.46 b	3.84 b
T_7	81.34 b	25.49 c	6.21 c	4.56 c	5.68 c	17.83 c	12.63 c	6.76 bc	1.93 c	1.67 c
T_8	35.29 cd	17.91 c	4.22 c	3.21 c	3.53 c	9.71 c	6.67 c	4.12 c	1.45 c	0.96 c
T_9	30.73 cde	16.06 c	3.73 c	2.84 c	3.12 c	8.59 c	5.9 c	3.64 c	1.28 c	0.86 c
T_{10}	45.18 c	23.93 c	5.90 c	4.28 c	5.01 c	14.3 c	10.23 c	5.85 c	1.75 c	1.52 c
T_{11}	35.06 cde	24.96 c	6.09 c	4.41 c	5.17 c	14.74 c	10.54 c	6.02 bc	2.02 c	1.34 c
HSD	16.14	22.84	6.52	5.02	5.91	21.17	13.16	9.69	2.30	1.95
Year means	-	-	-	-	-	-	-	-	**3.38 A**	**2.78 B**
HSD (years)	-	-	-	-	-	-	-	-	**0.432**	

T_1=Control (weedy check), T_2=Plastic sheet mulch, T_3=Pre-emergence application (PEA) of S-metolachlor at 1896 g a.i. ha^{-1}, T_4=PEA of S- metolachlor at 1896 g a.i. ha^{-1} and AWM @ 5 t ha^{-1} 40 days after sowing (DAS), T_5=PEA of S-metolachlor + directed post-emergence application (DPOEA) of glufosinate @ 600 g a.i. ha^{-1} 20 DAS, T_6=DPOEA of glufosinate at 20 DAS, T_7=DPOEA of glufosinate + AES Na salt @ 400 ml ha^{-1} at 20 DAS, T_8=DPOEA of glufosinate, 1st at 20 DAS, 2nd at 40 DAS, T_9=DPOEA of glufosinate + AESNa @ 400 ml ha^{-1}, 1st at 20 DAS, 2nd at 40 DAS, T_{10}=DPOEA of glufosinate + 2 % AMS at 20 DAS, T_{11}=DPOEA of glufosinate + 2 % AMS, 1st at 20 DAS, 2nd at 40 DAS. In a column, means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$). In a column, Means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$), *Values in parenthesis are percent reductions over weedy check.

Table 3. Contrast analysis of alligator weed growth traits under different weed control treatments.

Contrasts	Weed density (plants m^{-2})	Weed dry biomass (g m^{-2})	N-uptake (kg ha^{-1})	P-uptake (kg ha^{-1})	K-uptake (kg ha^{-1})	Fe-uptake (g m^{-2})	Mn-uptake (g m^{-2})	Zn-uptake (g m^{-2})	Cu-uptake (g m^{-2})	
	Two-year means								2015	2016
T1 vs C1	209.04 vs 37.57**	198.15 vs 18.71**	57.01 vs 4.50**	43.8 vs 3.21**	51.57 vs 3.95**	198.98 vs 11.74**	128.78 vs 8.36 **	67.55 vs 4.64**	19.14 vs 1.46**	16.41 vs 1.13**
C2 vs C3	-- vs 41.75**	-- vs 20.78^{NS}	-- vs 5.01^{NS}	--- vs 3.69 ^{NS}	-- vs 4.40^{NS}	-- vs 13.04^{NS}	-- vs 9.29*	--- vs 5.15**	-- vs 1.62^{NS}	-- vs 1.26^{NS}
C4 vs C5	17.67 vs 25.81**	7.59 vs 13.46**	1.66 vs 6.67 *	1.27 vs 4.90 *	1.30 vs 5.94 *	3.34 vs 17.9*	2.63 vs 12.61*	1.44 vs 7.01**	0.58 vs 2.14**	0.39 vs 1.69**
C6 vs C7	29.79 vs 21.837**	17.09 vs 9.82**	8.66 vs 4.68**	6.31 vs 3.48**	7.95 vs 3.94**	24.79 vs 11.01**	17.53 vs 7.7**	9.43 vs 4.59**	2.71 vs 1.58**	2.34 vs 1.05**
C8 vs C9	33.01 vs 22.22**	19.99 vs 10.18^{NS}	9.01 vs 5.34**	5.86 vs 3.94**	7.23 vs 4.65**	25.97 vs 13.86**	18.2 vs 9.82*	9.9 vs 5.56**	2.95 vs 1.74**	2.4 vs 1.34**

T1 = Weedy check, C1= all weed management treatments, C2 = Plastic sheet mulch, C3 = other weed management treatments, C4 = Treatments with pre-emergence herbicides, C5=treatments with post emergence herbicides, C6=Single application of glufosinate, C7= double application, C8=Glufosinate with adjuvant, C9= Glufosinate without adjuvant. NS = Not significant, **= Significant at 1% P, * indicates significant at 5% P.

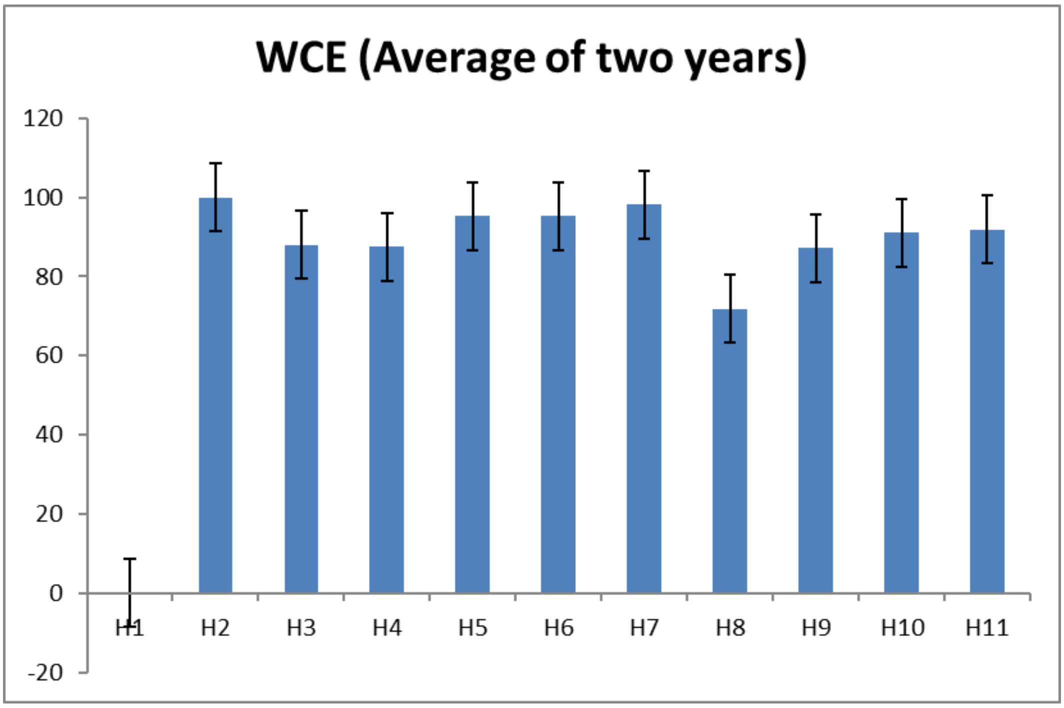

Figure 1. Comparison of weed control efficiencies (%) of experimental treatments

Table 4. Sunflower achene and oil yield and underlying traits under the influence of different weed control treatments

Treatments	Diameter of head (cm)		Per head achenes' count		Per head achenes' weight (g)		1000-achene Weight (g)	Achene yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
	2015	2016	2015	2016	2015	2016	Two-year means	2015	2016	2015	2016
T_1	12.53 e	13.68 e	710.8 f	738.4 f	24.31 d	25.25 d	33.98 h	1446.1 g (55.3%)*	1496.4 f (55.2%)*	423.7 g (68%)*	611.4 e (56%)*
T_2	17.99 a	19.54 a	1015.8 a	1055.3 a	49.81 a	51.74 a	48.66 a	3241.9 a	3341 a	1361.1 a	1402.7 a
T_3	15.55 cd	16.92 cd	879.5 cd	913.6 cd	37.20 bc	38.65 bc	42.10 bc	2104.6 d	2171.6 d	764.5 d	860.6 c
T_4	15.91 bc	17.30 bc	899.4 bc	934.4 bc	38.92 b	40.43 b	43.07 b	2391.6 c	2466.8 c	888.5 c	1026.7 b
T_5	17.36 ab	18.87 ab	962.8 ab	1000.4 ab	45.86 a	47.64 a	47.26 a	2672.2 b	2755 b	1058.6 b	1136.6 b
T_6	14.11 d	15.39 d	799.8 e	831 e	30.77 cd	31.97 cd	38.25 ef	1739.4 f	1799.2 e	573.3 f	749.6 cde
T_7	14.47 cd	15.78 cd	820.2 de	852.1 de	32.36 bc	33.62 bc	39.23 de	1748.4 ef	1807.8 e	591 f	706.6 de
T_8	15.12 cd	16.48 cd	856.4 cde	889.7 cde	35.28 bc	36.65 bc	36.46 fg	1800 ef	1859.6 e	635.9 ef	746.1 cde
T_9	15.14 cd	16.48 cd	856.6 cde	889.8 cde	35.29 bc	36.66 bc	40.99 cd	2025 d	2090.3 d	716 de	862.5 c
T_{10}	14.83 cd	16.16 cd	840.1 cde	872.8 cde	33.95 bc	35.28 bc	35.08 gh	1805.8 ef	1866.4 e	625.6 ef	766.8 cd
T_{11}	14.84 cd	16.17 cd	840.4 cde	872.9 cde	33.94 bc	35.28 bc	40.21 cde	1950.6 de	2014.3 de	676.5 def	839.4 cd
HSD	1.57	1.71	67.787	70.308	6.91	7.17	2.05	209.87	216.63	115.22	151.07
Year	16.62 A	15.26 B	895.51 A	861.97 B	36.16 B	37.56 A	39.66	2084.2 B	2151.7 A	755.88 B	805.14 A
HSD (years)	1.01		42.39		4.32		-	131.17		23.342	

T_1=Control (weedy check), T_2=Plastic sheet mulch, T_3=PEA of S-metolachlor @ 1896 g a.i. ha^{-1}, T_4=PEA of S- metolachlor @ 1896 g a.i. ha^{-1} and AWM @ 5 t ha^{-1} at 40 DAS, T_5=PEA of S-metolachlor + DPOEA of glufosinate @ 600 g a.i. ha^{-1}, T_6=DPOEA of glufosinate at 20 DAS, T_7=DPOEA of glufosinate + AES Na salt @ 400 ml ha^{-1} at 20 DAS, T_8=DPOEA of glufosinate, 1st at 20 DAS, 2nd at 40 DAS, T_9=DPOEA of glufosinate + AESNa @ 400 ml ha^{-1}, 1st at 20 DAS, 2nd at 40 DAS, T_{10}=DPOEA of glufosinate + 2 % AMS at 20 DAS, T_{11}=DPOEA of glufosinate + 2 % AMS, 1st at 20 DAS, 2nd at 40 DAS. In a column, means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$). In a column, Means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$). *Values in parenthesis are the percent reductions under fully uncontrolled alligator weedy conditions.

Table 5. Contrast analysis of sunflower achene and oil yield under the influence of different weed control treatments

Treatments	Diameter of head (cm)		Per head achenes' count		Per head achenes' weight (g)		1000-achene Weight (g)	Achene yield (kg ha^{-1})		Oil yield (kg ha^{-1})	
	2015	2016	2015	2016	2015	2016	Two year means	2015	2016	2015	2016
T1 vs C1	12.53 vs 15.53**	13.67 vs 16.9**	710.8 vs 877.1**	738.4 vs 911.2**	24.3 vs 37.34**	25.25 vs 38.79**	33.98 vs 41.13**	1446.1 vs 2147.95**	1496.4 vs 2217.2**	423.7 vs 789.1**	611.4 vs 909.76**
C2 vs C3	17.99 vs 15.53*	19.54 vs 16.61*	1015.8 vs 861.68**	1055.3 vs 895.18**	49.81 vs 35.95**	51.74 vs 37.35**	48.66 vs 38.82**	3241.9 vs 2026.4**	3341 vs 2092.3**	1361.1 vs 725.5**	1402.7 vs 854.98**
C4 vs C5	16.27 vs 14.75**	17.69 vs 16.07**	913.9 vs 835.58**	949.46 vs 868.05**	40.65 vs 33.6**	42.24 vs 34.91**	42.06 vs 37.20**	2389.4 vs 1844.8**	2464.4 vs 1906.2**	903.8 vs 636.3**	1007.9 vs 778.5**
C6 vs C7	14.47 vs 15.03**	15.77 vs 16.37**	820.03 vs 851.13**	851.96 vs 884.13**	32.36 vs 34.84**	33.62 vs 36.19**	36.23vs 38.17 **	1764.5 vs 1925.2**	1824.4 vs 1988.0**	596.6 vs 676.1**	741 vs 816**
C8 vs C9	14.61 vs 14.82^{NS}	15.93 vs 16.14^{NS}	828.1 vs 839.32*	860.35 vs 871.9^{NS}	33.02 vs 33.89^{NS}	34.31 vs 35.2 ^{NS}	39.23 vs 36.19^{NS}	1769.7 vs 1882.45^{NS}	1829.4 vs 1944.7 ^{NS}	604.6 vs 652.2^{NS}	747.8 vs 793.8 ^{NS}

T1 = Weedy check, C1= all weed management treatments, C2=Plastic sheet mulch, C3= other weed management treatments, C4=Treatments with pre-emergence herbicides, C5=treatments with post emergence herbicides, C6=Single application of glufosinate, C7= double application, C8=Glufosinate with adjuvant, C9= Glufosinate without adjuvant. In a column, Means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$). NS = Not significant, **= Significant at 1% P * indicates significant at 5% P.

Table 6. Economic analysis during year 2015.

Sunflower traits	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Remarks
Actual yield	1.45	3.24	2.10	2.39	2.67	1.74	1.75	1.80	2.03	1.81	1.95	Tones ha^{-1}
Stover value	9	10	9	10	10	9	9	9	9	9	9	US$ 0.070/40kg
Achene value	228	511	331	377	421	274	275	284	319	284	307	US$ 6.33/40 kg
Gross value	237	521	341	387	431	283	284	298	328	293	316	US$ ha^{-1}
Fixed Cost	268	268	268	268	268	268	268	268	268	268	268	US$ ha^{-1}
Herbicides cost	0	93	7	15	18	10	11	21	22	11	22	US$ ha^{-1}
Spray Charges/spread charges	0	4	4	5	7	4	4	7	7	4	7	US$ 850 ha^{-1}
Cost that vary	0	97	11	20	25	14	15	28	29	15	29	US$ ha^{-1}
Total Cost	268	365	279	288	293	282	283	296	298	283	298	US$ ha^{-1}
Net benefit	-32	156	61	99	138	0	1	2	30	10	18	US$ ha^{-1}
Benefit Cost Ratio		1.93	8.56	6.56	6.87	2.30	2.19	1.98	2.08	2.86	1.71	

T_1 = weedy check, T_2 = Plastic sheet mulch, T_3 = PE of S-metolachlor @ 1896 g a.i. ha^{-1}, T_4 = PE of S-metolachlor @ 1896 g a.i. ha^{-1} and alligatorweed AWM @ 5 t ha^{-1} at 40 DAS , T_5 = PE of S-metolachlor @ 1896 g a.i. ha^{-1} + DPO of glufosinate @ 600 g a.i. ha^{-1} at 20 DAS, T_6 = DPO of glufosinate @ 600 g a.i. ha^{-1} at 20 DAS, T_7 = DPO of glufosinate @ 600 g a.i. ha^{-1} + AESNa @ 400 ml ha^{-1} at 20 DAS, T_8 = DPO of glufosinate @ 600 g a.i. ha^{-1}, 1st at 20 DAS, 2nd at 40 DAS, T_9 = DPO of glufosinate @ 600 g a.i. ha^{-1} + AES @ 400 ml ha^{-1}, 1st at 20 DAS, 2nd at 40 DAS, T_{10} = DPO of glufosinate @ 600 g a.i. ha^{-1} + 2 % AMS at 20 DAS, T_{11} = DPO of glufosinate @ 600 g a.i. ha^{-1} + 2 % AMS, 1st at 20 DAS, 2nd at 40 DAS

Table 7. Economic analysis during year 2016

Sunflower traits	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Remarks
Actual yield	1.50	3.34	2.17	2.47	2.76	1.80	1.81	1.86	2.09	1.87	2.01	Tones ha^{-1}
Stover value	9	11	9	11	11	9	9	8	9	9	9	US$ 0.070/40kg
Achene value	236	526	342	389	434	283	285	293	329	294	317	US$ 6.33/40 kg
Gross value	245	537	351	399	445	292	294	301	338	303	326	US$ ha^{-1}
Fixed Cost	263	263	263	263	263	263	263	263	263	263	263	US$ ha^{-1}
herbicides cost	0	93	7	15	18	10	11	21	22	11	22	US$ ha^{-1}
Spray Charges/spread charges	0	4	4	5	7	4	4	7	7	4	7	US$ 850 ha^{-1}
Cost that vary	0	97	11	20	25	14	15	28	29	15	29	US$ ha^{-1}
Total Cost	263	360	274	283	287	277	277	290	292	277	292	US$ ha^{-1}
Net benefit	-18	177	78	117	157	16	16	11	46	26	34	US$ ha^{-1}
Benefit Cost Ratio	-	1.83	7.18	5.88	6.36	1.14	1.10	0.39	1.57	1.76	1.18	

T_1 = weedy check, T_2 = Plastic sheet mulch, T_3 = PE of S-metolachlor @ 1896 g a.i. ha^{-1}, T_4 = PE of S-metolachlor @ 1896 g a.i. ha^{-1} and alligatorweed AWM @ 5 t ha^{-1} at 40 DAS , T_5 = PE of S-metolachlor @ 1896 g a.i. ha^{-1} + DPO of glufosinate @ 600 g a.i. ha^{-1} at 20 DAS, T_6 = DPO of glufosinate @ 600 g a.i. ha^{-1} at 20 DAS, T_7 = DPO of glufosinate @ 600 g a.i. ha^{-1} + AESNa @ 400 ml ha^{-1} at 20 DAS, T_8 = DPO of glufosinate @ 600 g a.i. ha^{-1}, 1^{st} at 20 DAS, 2^{nd} at 40 DAS, T_9 = DPO of glufosinate @ 600 g a.i. ha^{-1} + AESNa @ 400 ml ha^{-1}, 1^{st} at 20 DAS, 2^{nd} at 40 DAS, T_{10} = DPO of glufosinate @ 600 g a.i. ha^{-1} + 2 % AMS at 20 DAS, T_{11} = DPO of glufosinate @ 600 g a.i. ha^{-1} + 2 % AMS, 1^{st} at 20 DAS, 2^{nd} at 40 DAS