Phyton-International Journal of Experimental Botany
DOI:10.32604/phyton.2020.08536
Article

Comparative Efficacy of Weed Control Practices for Parthenium Weed and Sunflower Crop under Varying Tillage Systems

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Received: 05 September 2019; Accepted: 13 November 2019

Abstract: Parthenium poses serious threat to modern crop production system and necessitate evaluating control practices for its effective management. Efficacy of different weed control practices for controlling parthenium was explored in conventional and deep tillage systems in the field conditions. Hand hoeing (20 and 35 days after emergence), S-Metolachlor (pre-emergence herbicide), sorghum straw mulch @ 5 tons ha^{-1} and combination of hand hoeing and sorghum straw mulch (hand hoeing at 20 and straw mulch at 35 days after emergence) were used as weed control practice. Weedy check where no weed control measure was applied was also included in this experiment for comparison. Results concluded that the all weed management treatments significantly reduced parthenium density, its fresh and dry biomass during both the years of study as compared to weedy check. Maximum sunflower achene yield was recorded in hand hoeing (20 and 35 days after emergence) in combination with deep tillage. So, mold bold plough used for the purpose of deep tillage should be encouraged for better control of parthenium and higher achene yield of sunflower crop (3293.3 kg ha^{-1} in 2017 and 3221.3 kg ha^{-1} in 2018). Moreover, is also inferred that total dose of herbicide might be reduced by using hoeing and mulching in an integrated way.

Keywords: Parthenium; mulch; hoeing; tillage; s-metolachlor; sunflower

1 Introduction

Sunflower (*Helianthus annuus* L.) stands as an astounding candidate to fulfil our domestic oil needs. Sunflower fulfils 14% edible oil needs of the world [1]. It is ranked fourth in oil seeds just after soybean, palm and canola oil. Sunflower oil is rich in poly unsaturated fatty acids [1]. Its achene contains up to 51% fats in it [2]. Sunflower produces good quality oil and it was grown on 203 thousand acres (with production of 40 thousand tons of oil) but its yield in our country is much lower than its potential yield [3]. Several factors are responsible for low yield in sunflower, i.e., competition with major crops, poor marketing, lack of subsidies by government, improper seed rate and sowing time, attack of insect pest and disease and especially weeds [1].

One third of yield losses caused by agricultural pests are posed by only weeds. Weeds are important but neglected factor, responsible for yield reduction. Weeds can compete for nutrients, water space and light [4].

Weeds, if not controlled properly are capable of reducing sunflower's yield up to 90%. A well-managed weed control plan is essential for successful crop production [5]. Invasive weeds are troublesome worldwide regarding biodiversity and crop production [6] because of their competitiveness and capabilities to settle themselves in new environment in very short time. *Parthenium hysterophorus* L. is the best example in our country which is a native to America and Maxico [7]. It is member of Asteracea family. It is a broad leave plant with tap root system. Its florescence is termed as achene. This plant can grow and reproduce throughout the year and is hard enough to complete its life cycle in only four weeks when environmental conditions are not favourable [6]. Fast germination rate, rapid growth, production and release of allelochemicals, persistent and large seed bank and prolonged dormancy made this weed well adapted to indo-pak subcontinent where it is negatively affecting the crop production [5]. More than 40 countries of the world are suffering from problems created by Parthenium and it is like a headache for farmers in Ethiopia, South Africa, Kenya, Mozambique, Swaziland, Mauritius, Zimbabwe and Madagascar [8]. The problems caused by this weed are related to animal, human, plant and environmental health. This weed is responsible for decline in productivity of livestock, pastures, biodiversity as well as crops [9]. Besides reducing yield of crops and pastures, Parthenium taints meat and milk of animals when consumed by them. It reduces the quality of land and animals and causes asthma, hay fever, dermatitis and allergy problems in humans [6]. Genetic diversity of this plant express itself as variation in plant height, rooting depth and number and size of flowers, leaves and seeds in different countries of the world. So, it can grow in wide range of prevailing environmental conditions [10]. It has entered Pakistan through India and is becoming future threat for Asian countries like India, Bangladesh, Nepal and Vietnam [9]. It has gained tenth position among worst weeds of the world [11]. In Pakistan Parthenium is growing dominantly along railway sides, pastures, lawns, waste lands, agro ecosystems, graveyards and field crops [12]. It is capable of producing flowers throughout the year and can produce 1500 to 2500 seeds per plant [5]. A decline of herbaceous component of natural plant community can be up to 90% owing to this alien weed [13]. Parthenium, when invades agricultural crops leads to crop failure because it can reduce crop yield by 40–97% [14]. Parthenium is now a days spreading in field crops in the country owing to favorable conditions for its growth [12].

Chemical weed control can produce 40–97% higher yield as compared to un-weeded crop [11]. Controlling weeds with herbicides ensures efficient weed control [15]. But higher cost of herbicides, their negative impact on human and environmental health are some of the draw backs. Herbicides are also needed to be applied repeatedly because weeds re-emerge from their seed bank [6]. Tillage not only destroys already germinated weeds but also buries the weed's seed present on the surface by decreasing the weeds population afterwards. Deep tillage implements like, mould board plough has weed seed burying ability. Seeds buried in lower soil layers are less likely to grow due to physical hindrance of above soil layers. In other words, mould board plough reduces the probability of emergence of weed seed. In developing countries like Pakistan ploughing as well as use of herbicides is suggested as efficient management strategy for Parhtenium [5]. Hand hoeing not only controls weeds but also improves soil physical health. In tropics manual weeding and tillage are most frequently used to control weeds [16]. Brown et al. [17] and Narender et al. [18] reported that the mulching with straw is an efficient method for the controlling of weeds. Allelopathic mulches are efficient way of weed control. Emerging seedlings are controlled efficiently by leaching of allelochemicals through mulches. Sorghum is an allelopathic crop and its straw mulch significantly reduces weed density in many field crops. Any single method of weed control does not give proper control. For minimizing the infestation of invasive alien weeds all the viable and affordable measures should be adapted in an integrated manner. It is because some of the weed plants will be controlled by one method and the leftovers will be controlled by other control methods, ensuring maximum possible weed control [18]. Aim of study was evaluate the response of sunflower crop and Parhtenium weed by using different tillage practice for controlling of weeds and enhance the production of sunflower.

2 Materials and Methods

Two Field experiments were carried out at Post Graduate Agricultural Research Station, University of Agriculture Faisalabad (31.26° N, 73.06° E and 184.4 m Altitude) during 2017 and 2018. Physico-chemical analysis of soil was given in Tab. 1. Data regarding weather conditions during growing season (February, March, April and May) of autumn sunflower were collected from Agriculture Meteorology cell situated in University of Agriculture, Faisalabad, Pakistan (Tab. 2).

Table 1: Physiological and chemical analysis of the soil used in experiments at University of Agriculture, Faisalabad (UAF), Pakistan

Soil Characteristics	2017			2018		
	15 cm	30 cm	Mean	15 cm	30 cm	Mean
pH of soil	8.1	7.9	8	8.1	9.1	8.6
EC (dS m^{-1})	0.61	0.51	0.56	0.61	0.58	0.695
Organic matter (%)	0.78	0.56	0.67	0.79	0.57	0.68
Total Nitrogen (%)	0.04	0.03	0.035	0.05	0.04	0.045
Available Phosphorus (ppm)	9.7	7.5	8.6	10.8	8.9	9.85
Available Potassium (ppm)	196	216	206	199	219	209
Texture	Sandy clay loam			Sandy clay loam		

Table 2: Climatic conditions prevailed during study in University of Agriculture Faisalabad in 2017 and 2018

Month	Temperature (°C)						Relative Humidity (%)		Total Rainfall (mm)	
	Maximum		Minimum		Mean					
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
February	23.3	24.0	10.2	9.5	16.8	16.7	53.3	73.3	4.1	9.5
March	27.3	31.2	14.2	16.4	20.7	23.8	49.5	61.4	16.2	12.5
April	37.7	36.8	20.9	20.8	29.3	28.8	30.6	47.3	28.3	7.9
May	41.1	40.3	26.0	23.7	33.5	32.0	29.8	29.8	10.1	21.6
Total									58.7	51.5

2.1 Experiment Design, Treatments and Studied Traits

Two factor factorial experiment was designed following randomised complete block design with three replications. Factor A (tillage) includes T_1 = Conventional tillage (2 times cultivation followed by planking) and T_2 = Deep tillage (MB plough followed by single cultivation and planking). Factor B (weed control measures) include C_1 = Weedy check, C_2 = Hand hoeing1 (20 and 35 days after emergence), C_3 = Sorghum straw mulch @ 5 tons ha^{-1}, C_4 = Hand hoeing2 (20 days after emergence) + sorghum straw mulch @ 5 tons ha^{-1} and C_5 = S-metolachlor @ 1896 g ha^{-1}. In field experiments, sunflower variety Hysun-33 was sown in the month of February on 75 cm apart ridges with plant to plant distance of 23 cm using randomized complete block design under split plot arrangement. Quantity of water and herbicide was calculated before spraying. Hand operated Knapsack/sprayer fitted with nozzle was used. Agronomic practices (excluding those under study) were kept uniform. Data were recorded on yield and yield components of sunflower, i.e., plant population per plot, plant height (cm), head diameter (cm), stem diameter (cm), number of achenes per head, weight of achene per head, achene number per head, biological yield (t ha^{-1}), achene yield (kg ha^{-1}), oil yield (t ha^{-1}), stover yield (t ha^{-1}) and harvest index (%), quality parameters, i.e., achene oil content (%) and achene protein content (%), and weed parameters, i.e., weed density (plants m^{-2}), weed fresh weight (g m^{-2}) and weed dry weight (g m^{-2}).

2.2 Determination of Achene Oil Contents (%)

Sample of sunflower achenes was heated in the oven at 50°C in an oven for 16 hours and then was grinded. Oil contents were determined using Soxhlet method [19] by which sunflower's achene powder of three grams was wrapped in a filter paper. Bult extraction tube was assembled and this sample was placed in it. Petroliam ether @ 170 ml was added in the tarred extraction flask, before assembling the apparatus. Apparatus was heated on hot plates to 60°C. It was then disjointed and cooled. W_1 was achieved by pouring contents of extraction tube into a petri dish. This petri dish was heated to 100°C in an oven till constant weight W_2. For determining oil percentage following formula was used.

$$\text{Oil content (\% age)} = \frac{W_2 - W_1}{\text{Sample weight}} \times 100$$

2.3 Determination of Achene Protein Contents (%)

Micro-Kjeldhal distillation procedure was used to determine the nitrogen contents of sunflower achene sample [20]. Following formula was used to determine final crude protein,

% Crude protein = % Nitrogen × 6.25

Sunflower sample, after drying were ground using an electrical grinder. Sample was digested according to Wolf [21] method.

2.4 Statistical Analysis

Fisher's analysis of variance technique was used to analyze the data statistically and Tukey's honestly significant difference (HSD) was used to compare different treatment means at 5% probability value [22] by using Statistix 8.1 software.

3 Results and Discussion

3.1 Plant Population (cm) and Plant Height (cm) of Sunflower

Individual as well as interactive effect of tillage systems and other weed control practices on plant population were found non-significant during both the years because row to row and plant to plant distance was kept uniform (Tab. 3).

Effect of different tillage systems and their interaction with different weed control practices was non-significant ($p \leq 0.05$) on plant height of sunflower. However different weed control practices affected plant height significantly. Statistically maximum plant height (188.33 cm) was recorded in hand hoeing1. In the following year (2018) effect of different tillage systems, weed control practices as well as their mutual interaction was statistically ($p \leq 0.05$) significant in affecting plant height of sunflower. Deep tillage × hand hoeing1 produced maximum plant height (186.67 cm) which was statistically like the plant height (187.3 cm) recorded in deep tillage × hand hoeing2. Plant height (117.33 cm) recorded from weedy check in combination with conventional tillage was statistically minimum in year 2018 (Tab. 3). Present study was supported by the Simic et al. [23] discovered that sunflower plants were taller in herbicide treated plots as compared to un-weeded control treatment. These results are also in agreement with those of Saudy et al. [24]. They applied butralin + prometryn + two hand weeding and recorded taller sunflower plants in this treatment. These results are also supported by findings of Balasubramanian et al. [25] who explored the efficacy of different herbicides alone and in combination with hand weeding

Table 3: Effect of tillage systems and different weed control practices on plant population per plot, plant height (cm), head and stem diameter (cm) of sunflower in 2017 and 2018

Plant population per plot	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	5.78	5.77	5.77	5.78	5.78	5.77	5.77	5.76	5.76	5.78	5.77	5.77
Deep tillage	5.77	5.77	**5.76**	5.76	5.77	5.78	5.78	5.77	5.77	5.76	5.76	5.78
Mean	**5.75**	**5.76**	**5.76**	**5.78**	**5.76**	**5.75**	5.78	**5.76**	**5.76**	**5.76**		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											

Plant height (cm)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	132.33	117.3 E	**189.00**	156.33 b	149.67	138.67 cd	169.67	155.73 b	152.33	136.67 d	158.60	140.95 B
Deep tillage	132.33	131.20 de	**187.67**	186.67 a	150.00	151.67 bc	168.67	187.33 a	153.00	152.00 bc	158.33	161.77A
Mean	132.33 D	124.27 C	**188.33 A**	171.50 A	149.83 C	145.17 B	169.17 B	171.53 A	152.67 C	144.33 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											

Head diameter (cm)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	13.03	11.65	18.86 AB	15.21	16.56	15.18	17.43	15.37	16.20	14.82	16.42 B	14.44 B
Deep tillage	14.80	13.38	21.10 A	18.62	17.83	16.45	19.26	18.89	18.40	17.02	18.28 A	16.87 A
Mean	13.91C	12.51B	19.98A	16.91 A	17.20 B	15.82 A	18.35 B	17.13 A	17.30 B	15.92 A		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											

Stem diameter (cm)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	1.47	1.38	2.01	1.64	1.49	1.47	1.76	1.73	1.62	1.47	1.67	1.54 B
Deep tillage	1.47	1.46	2.00	1.98	1.64	1.62	1.75	1.98	1.60	1.58	1.69	1.72 A
Mean	1.47 D	1.53 B	2.00 A	1.86 A	1.56 CD	1.54 B	1.76 B	1.81 A	1.61 C	1.42 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											

In a column, Means sharing different letters statistically significant based on Tukey's HSD test ($p \leq 0.05$) NS = Non-significant, values in bracts presents 2018.

at different stages in sunflower. Zhao et al. [26] evaluated the performance of wheat, maize and sunflower mulch in growing sunflower crop and recorded taller plants in mulched plots as compared to non-mulched.

3.2 Head Diameter (cm) of Sunflower

Larger heads of sunflower usually give better yield. Results presented in Tab. 3 indicate that head diameter of sunflower is affected significantly by tillage systems and different weed control practices in both study years. However, interaction between main effects was non-significant in both the experimental years. During first year of experiment (2017), Maximum value of head diameter in 2017 (18.28 cm) and in 2018 (16.87 cm) was recorded in deep tillage plots and was statistically higher than mean value of head diameter recorded (14.44 cm) from conventional tillage. Larger heads were produced in experimental plots where weed control practices were applied than un-weeded check treatment. It happened because in these plots' competition pressure posed by parthenium was lesser and sunflower used air, light, water, nutrients, soil and other resources very efficiently. Head diameter was increased by applying S-metolachlor (1.6 L ha^{-1}) [27]. These results are also in agreement with those of Shylaja et al. [28]. They stated that double hand hoeing produced heads with increased diameter. Zhao et al. [26] found that wheat, maize and sunflower stover when used as mulch improved water use efficiency and head diameter of sunflower. Results were more convincing when mulching stovers were supplemented with plastic mulch.

3.3 Stem Diameter (cm) of Sunflower

Effect of tillage systems and their interaction with different weed control practices is non-significant. However different weed control practices have significant ($p \leq 0.05$) effect on stem diameter of sunflower during 2017. Statistically maximum value of stem diameter (2.00 cm) is recorded from hand hoeing1. In following year 2018, tillage systems and different weed control practices affected stem diameter of sunflower significantly however their mutual interaction was non-significant ($p \leq 0.05$). In weed control practices, hand hoeing2 produced maximum stem diameter (1.81 cm) that was statistically at par with stem diameter (1.86 cm) recorded from hand hoeing1 (Tab. 3). These results are supported by those of Shah et al. [27] who applied full dose of S-metolachlor @ 1.6 L ha^{-1} and its one third quantity + sorghaab to control weeds in sunflower and found thicker stems (2.49 cm) in both of the treatments while thinner stems (1.85 cm) were produced in un-weeded check treatment. Akbari et al. [29] also revealed that sowing date and different weed control practices affect stem diameter of sunflower significantly. Results of experiments conducted by Koutroubas et al. [30] are in contrary with ours as they claimed application of Paclobutrazol does has no significant effect on stem diameter. Thicker and healthies stems of sunflower were recorded by Zhao et al. [26] when they used maize, wheat and sunflower as mulching material to produce sunflower crop.

3.4 Number of Achenes per Head of Sunflower

Results presented in Tab. 4 indicate that number of achenes per head of sunflower is affected significantly ($p \leq 0.05$) by tillage systems and different weed control practices in both years. Interaction between main effects was also significant. Maximum number of achenes per head 1111 were recorded from deep tillage in combination with hand hoeing1. In the second year of experiment (2018), mutual interaction of main effects was non-significant. Deep tillage produced 897.1 achenes per head while conventional tillage produced 816.3 achenes per head. Deep tillage produces statistically higher value of number of achenes per head. In weed control practices, hand hoeing2 produced maximum number of achenes per head 986.0 that was statistically at par with 973.8 achenes per head in hand hoeing1. Higher value of number of achenes per head in weed control practices as compared to un-weeded check treatment depicts the efficiency of these control measures for parthenium. These results are in line with those of Singh et al. [31] who recorded significant increase in number of achenes per head by applying

Table 4: Effect of tillage systems and different weed control practices on number of achene's per head, weight of achene per head, 1000-achene weight (g) and biological yield (kg ha^{-1}) of sunflower in 2017 and 2018

Number of achene's per head	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	728.3 g	703.5	955.7 c	891.0	821.3 e	786.8	898.7 d	914.3	821.3 E	786.3	845.07 B	816.39 B
Deep tillage	797.0 f	762.2	1111.0 a	1056.7	820.3 e	805.1	989.7 b	1057.8	819.7 E	804.0	907.53 A	897.16 A
Mean	762.7 D	732.88 C	1033.3 A	973.83 A	820.8 C	795.93 B	944.2 B	986.06 A	820.5 C	795.16 B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Weight of achene per head (g)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	24.33 D	23.41 d	40.70 b	39.78 b	32.53 c	31.61 bc	39.03 b	40.13 b	31.13 C	30.21 c	33.54 B	33.03 B
Deep tillage	29.42 cd	28.50 cd	55.15 a	54.23 a	41.35 b	40.43 b	51.66 a	54.34 a	41.25 B	40.33 b	43.76 A	43.56 A
Mean	26.87 D	25.95 C	47.92 A	47.00 A	36.94 C	36.02 B	45.34 B	47.24 A	36.19 C	35.27 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											
1000-achene weight (g)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	32.40 f	32.00 e	42.66 Bc	42.26 b	39.21 de	38.81 cd	40.20 cd	41.39 bc	39.14 De	38.74 cd	38.72 B	38.64 B
Deep tillage	36.91 e	36.51 d	49.66 A	49.26 a	43.70 b	43.30 b	47.73 a	49.61 a	43.62 B	43.22 b	44.32 A	44.38 A
Mean	34.65 D	34.25 C	46.16 A	45.76 A	41.45 C	41.05 B	43.96 B	45.50 A	41.38 C	40.98 B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Biological yield (kg ha^{-1})	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	7347	6097	10079	8745	8892	7641	9661	8704	8888	7638	8973 B	7765 B
Deep tillage	7970	6720	10719	9469	9822	8785	10441	9502	9811	8805	9752 A	8656 A
Mean	7659 C	6408 C	10399 A	9107 A	9357 B	8213 B	10051 A	9103 A	9350 B	8221 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											

In a column, Means sharing different letters statistically significant based on Tukey's HSD test ($p \leq 0.05$) NS = Non-significant, values in bracts presents 2018.

pendimethalin @ 1 kg a.i ha^{-1}. Number of achenes per head in sunflower was also increased by applying two hand hoeing (15 and 30 DAS) and it was statistically at par with fluchloralin application @ 1.5 kg a.i ha^{-1} + intercropping with black gram [28]. These results are also in agreement with those of Shah et al. [27] who used S-metolachlor as pre-emergence herbicide in sunflower. Number of achenes per head were increased when sunflower and maize stover was used as mulching material to grow and produce sunflower crop [26].

3.5 *Achene's Weight (g) per Head of Sunflower*

Tillage systems as well as weed control practices have significant effect on per head achene weight of sunflower. Interaction between tillage and different weed control practices is also significant ($p \leq 0.05$) in both the experimental years. During 2017, statistically maximum value of achene weight in 2017 (51.66 g) and in 2018 (54.23 g) per head was recorded in deep tillage × Hand hoeing2 (Tab. 4). Higher values of achene weight per head were recorded because weed control practices controlled parthenium significantly by allowing sunflower to use resources and to fix them in the form of achenes. Application of Butralin + prometryn resulted in 50% increase in seed weight per plant when compared to un-weeded plot [24]. However, these results are in contrary with those of Simic et al. [23] who conducted an experiment to explore interference of kochia in sunflower and discovered non-significant effect of different densities competing for different durations. Mulching material increased the water holding capacity and sunflower yield in saline areas. In saline areas sunflower yield and achene weight was recorded higher when sunflower and maize stover was used as mulching material [26].

3.6 *Thousand Achene Weight (g) of Sunflower*

During both experimental years, different weed control practices and tillage systems significantly affected thousand achene weight of sunflower. The interaction between main effects was also significant. In 2017, deep tillage × hand hoeing2 and deep tillage × hand hoeing1 were statistically at par by producing highest values of thousand achene weight (47.73 g) and (49.66 g), respectively. Similarly, during 2018, statistically maximum ($p \leq 0.05$) thousand achene weight (47.61 g) was obtained in deep tillage × hand hoeing2 and it was at par with thousand achene weight (49.26 g) produced by deep tillage × hand hoeing1 (Tab. 4). Significantly higher values of 1000 achene weight in weed control practices reflect that these practices significantly lowered parthenium density. Highest value of 1000 achene weight in sunflower was recorded when one third of recommended dose of S-metolachlor @ 1.6 L ha^{-1} + sorghaab@ 15 L ha^{-1} was applied two times. Singh et al. [31] also recorded similar findings when they applied pendimethalin @ 1 kg a.i ha^{-1} in sunflower. Thousand achene weight and sunflower yield was higher in mulch treatment as compared to non-mulched plots. Water holding capacity of soil was improved by adding mulch in sunflower field [26].

3.7 *Biological Yield (kg ha^{-1}) of Sunflower*

Tillage systems and different weed control practices affected biological yield of sunflower significantly ($p \leq 0.05$) in both study years however interaction between main effects was statistically non-significant. In first experimental year (2017), deep tillage produced biological yield (9752 kg ha^{-1}) which was higher than biological yield (8973 kg ha^{-1}) produced by conventional tillage. In weed control practices, hand hoeing2 and hand hoeing1 produced statistically highest values of biological yield (10051 kg ha^{-1}) and (10399 kg ha^{-1}), respectively which were at par with each other. Similarly, during 2018, (8656 kg ha^{-1}) and (7765 kg ha^{-1}) biological yields were produced by deep tillage and conventional tillage, respectively. Deep tillage produced statistically higher value of biological yield. In weed control practices, biological yields (9103 kg ha^{-1}) and (9107 kg ha^{-1}) were recorded in hand hoeing2 and hand hoeing1, respectively (Tab. 4). Demir et al. [32] compared the performance of mouldboard plough, reduced tillage and no tillage systems and recorded highest gross biological yield of sunflower in mouldboard plough treatment. Higher biological yield in all weed control practice is due to better control of parthenium in these treatment as compared to un-weeded check treatment allowing sunflower to use the required resources more efficiently than un-weeded plot. Sunflower is highly competitive with weeds when it gets established but weed control practices are very necessary because it is vulnerable to weed at early and slow growth stages [33]. Highest biological yield was recorded in sunflower when one third dose of S-metolachlor @ 1.6 L/ha + sorghaab@15 L/ha was applied in sunflower [27].

3.8 Achene Yield (kg ha^{-1}) of Sunflower

Achene yield of sunflower is significantly affected by tillage systems and different weed control practices. Interaction between main effects was also significant in both the experimental years. During 2017, statistically maximum value of achene yield of sunflower (3293.3 kg ha^{-1}) was recorded in deep tillage × hand hoeing1. During 2018, deep tillage × hand hoeing2 produced statistically maximum achene yield (3221.3 kg ha^{-1}) which was at par with achene yield (3220.3 kg ha^{-1}) produced by deep tillage × hand hoeing 1 (Tab. 5). Weeds are primarily controlled from arable crops to avoid the yield losses. Simic et al. [23] explored the effect of kochia in sunflower and concluded that sunflower yield was not affected significantly by applying herbicides at beginning but at later stages when weed continued its growth there was significant difference of achene yield of sunflower in herbicide treated plots as compared to un-treated ones. Findings of Channappagoudar et al. [34] are also in line with ours. Results of this experiment are also in line with those published by Demir et al. [32]. They compared the performance of mouldboard plough with reduced and no tillage systems and recorded highest gross yield by mouldboard plough.

3.9 Oil Yield (kg ha^{-1}) of Sunflower

Oil yield of sunflower is significantly affected by tillage systems and different weed control practices. Interaction between main effects is also significant in first experimental year. Statistically maximum oil yield (1354.3 kg ha^{-1}) was recorded in deep tillage × hand hoeing1. During second year of experiment tillage systems and different weed control practices significantly affected the oil yield of sunflower while interaction effect was found non-significant ($p \leq 0.05$). In tillage systems, deep tillage gave higher oil yield (999.27 kg ha^{-1}) as compared to oil yield (692.67 kg ha^{-1}) of conventional tillage system. In weed control practices, statistically highest oil yield (1079.5 kg ha^{-1}) was obtained in hand hoeing1 and it was at par with oil yield (1045.3 kg ha^{-1}) obtained from hand hoeing (Tab. 5). Findings of Shah et al. [27] are also in close agreement with ours. Herbicide treated plots produced 336 kg ha^{-1} more oil as compared to unweeded check treatment. Our results are also in agreement with those presented by Moitzi et al. [35]. They compared the performance of mouldboard plough with conventional deep tillage, conventional shallow tillage and no tillage systems.

3.10 Stover Yield (kg ha^{-1}) of Sunflower

Tillage systems as well as weed control practices affected Stover yield of sunflower significantly ($p \leq 0.05$) whereas interaction effect was found non-significant in both the experimental years. During first experimental year, (5901.7 kg ha^{-1}) Stover yield was recorded in deep tillage and it was statistically higher than Stover yield (5356.3 kg ha^{-1}) of conventional tillage. In weed control practices, hand hoeing1 gave highest Stover yield (6048.0 kg ha^{-1}) and it was statistically like Stover yield (5921.3 kg ha^{-1}) recorded from hand hoeing2. During next year, deep tillage gave higher Stover yield (5740.9 kg ha^{-1}) as compared to Stover yield (5201.9 kg ha^{-1}) of conventional tillage system. In weed control practices statistically highest Stover yield (5860.2 kg ha^{-1}) was achieved from hand hoeing2 and it was statistically like Stover yield (5846.3 kg ha^{-1}) achieved from hand hoeing1 (Tab. 5). Similar 11 results were obtained by Sumathi et al. [36] who applied Pendimethalin applied @ 1.0 kg ha^{-1} as pre-emergence herbicide and recorded significantly higher stover yield of sunflower that was statistically at pat with stover yield recorded from experimental plots where Fluchloralin @ 1.0 kg a.i ha^{-1} + two hand hoeing was applied. Higher stalk yield was also recorded by Nagamani et al. [37] when they applied Pendimethalin @ 1.0 kg ha^{-1} + single hand hoeing after 30 days of sowing. Moitzi et al. [35] recorded highest energy efficiency of conventional shallow tillage system as compared to mouldboard plough in experiment conducted for twelve years.

Table 5: Effect of tillage systems and different weed control practices on achene yield (kg ha^{-1}), oil and Stover yield (t ha^{-1}) and harvest index (%) of sunflower in 2017 and 2018

Achene yield (kg ha^{-1})	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	18.65	21.96	27.06	30.40	22.81	26.10	25.65	30.76	23.18	26.50	23.47 B	27.14 B
Deep tillage	21.88	25.20	31.33	34.63	28.01	31.33	30.31	34.66	28.41	31.73	27.98 A	31.51 A
Mean	20.27 C	23.58 C	29.20 A	32.51 A	25.41 B	28.71 B	27.98 A	32.71 A	25.79 B	29.11 B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Oil yield (t.ha^{-1})	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	427.3 e	485.0	1011.7 abc	889.7	782.0 Cd	697.0	877.3 bcd	840.0	779.3 Cd	694.3	775.5 B	692.67 B
Deep tillage	570.0 de	342.3	1354.3 a	1269.3	1075.3 abc	1002.0	1197.0 ab	1250.7	1067.7 abc	989.3	1052.9 A	999.27A
Mean	498.7 C	413.7 C	1183.0 A	1079.5 A	928.7 B	849.5 B	1037.2 AB	1045.3 A	923.5 B	841.8 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											
Stover yield (t ha^{-1})	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	4805.3	4630.3	5841.0	5666.0	5184.7	5009.7	5762.7	5691.0	5187.7	5012.7	5356.3 B	5201.9 B
Deep tillage	5275.7	5100.7	6255.0	6026.7	5969.7	5794.7	6080.0	6029.3	5928.3	5753.3	5901.7 A	5740.9 A
Mean	5040.5 C	4865.5 C	6048.0 A	5846.3 A	5577.2 B	5402.2 B	5921.3 A	5860.2 A	5558.0 B	5383.0 B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Harvest Index (%)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	18.65	21.96	27.06	30.40	22.81	26.10	25.65	30.76	23.18	26.50	23.47 B	27.14 B
Deep tillage	21.88	25.20	31.33	34.63	28.01	31.33	30.31	34.66	28.41	31.73	27.98 A	31.51 A
Mean	20.27 C	23.58 C	29.20 A	32.51 A	25.41 B	28.71 B	27.98 A	32.71 A	25.79 B	29.11 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											

In a column, Means sharing different letters statistically significant based on Tukey's HSD test ($p \leq 0.05$) NS = Non-significant, values in bracts presents 2018.

3.11 Harvest Index (%) of Sunflower

Tillage systems and different weed control practices affected harvest index of sunflower significantly ($p \leq 0.05$) in both the experimental years however interaction between main effects was non-significant. In first experimental year (2017), deep tillage produced harvest index (27.98%) which was higher than harvest index (23.47%) produced by conventional tillage. In weed control practices, hand hoeing produced statistically highest values of harvest index (27.98%) and (29.20%) which were at par with each other. During year 2018, (31.51%) and (27.14%) harvest index were produced by deep tillage and conventional tillage, respectively. Deep tillage produced statistically higher value of harvest index. In weed control practices, harvest index (32.71%) was recorded in hand hoeing1. Weedy check where no weed control practice was used, produced statistically minimum harvest index (23.58) (Tab. 5). Harvest index was recorded higher in weed control practices as in these treatments vegetative growth was lesser than reproductive growth. In un-weeded check its value was lower because here weeds used the resources that would otherwise be used and fixed by sunflower into economic yield. Findings of Shah et al. [27] are also in close agreement with ours who stated that application of S-metolachlor (one third of 1.6 L/ha) + sorghaab @15 L/ha gave highest value of stover yield in sunflower. Marwat et al. [38] stated that harvest index was increased because weeds were controlled properly to ensure the availability of nutrients to sunflower that enabled it to produce higher economic yield. Moitzi et al. [35] reached similar conclusions when they tested the performance of mouldboard plough in winter wheat in twelve years of experiment.

3.12 Quality Parameters

3.12.1 Achene Oil Contents (%) of Sunflower

Achene oil contents are genetically influenced and less affected by environment because during both years of study tillage systems and different weed control practices had non-significant effect on achene oil contents of sunflower. Interaction effect was also non-significant for both the experimental years (Tab. 6).

3.12.2 Achene Protein Contents (%) of Sunflower

Effect of different weed control practices, tillage systems and their mutual interaction is non-significant in affecting achene protein contents (%) of sunflower. Like achene oil contents, it is also genetically controlled trait which is less affect by environment (Tab. 6).

3.13 Weed Parameters

3.13.1 Weed Density (Number of Parthenium Plants m^{-2})

Weed density is inversely related to the crop yield in any field as weeds compete with crop and steal resources to complete their life cycle. Results for effect of tillage systems and different weed control practices on number of parthenium plants (Tab. 7). Tillage systems as well as different weed control practices significantly affected parthenium density. Interaction between tillage systems and weed control practices is also significant for both the experimental years. During experimental year (2017), statistically maximum number of parthenium plants 50.33 m^{-2} were recorded in weedy check in combination with conventional tillage. During second year of experiment (2018), statistically maximum number of parthenium plants 60.00 m^{-2} were recorded from weedy check × conventional tillage. It was followed by number of parthenium plants 48.33 m^{-2} in weedy check in combination with deep tillage. Lower weed density in all the treatments as compared to un-weeded treatment reflects their efficiency. Results of this experiment agree with findings of Balasubramanian et al. [25]. They recorded significantly lower weed densities in herbicide treated plots. They tested the performance of different pre and post emergence herbicides alone and in combination with hand weeding in sunflower at different stages of development. They claimed that fluchloralin @ 1.5 kg ha^{-1} when combined with hand weeding 30 days after sowing was most efficient of all the treatments. Beres et al. [39] also reported significance of different post emergence herbicides in controlling weeds in sunflower. Baskaran et al. [40] explored the

Table 6: Effect of tillage systems and different weed control practices on oil contents and protein quality (kg ha^{-1}) of sunflower in 2017 and 2018

Oil contents (%)	Weedy check		Double hand hoeing		Sorghum straw mulch		Hoeing+ mulch		S-metolachlor		Mean	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Conventional tillage	427a	485	1012abc	890	782cd	697	877bcd	840	779cd	694	776b	693b
Deep tillage	570de	342	1354a	1269	1075abc	1002	1197ab	1251	1068abc	989	1060a	999a
Mean	499c	414c	1183a	1080a	928b	850b	1037ab	1045a	923b	842b		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Protein contents (%)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	21.12	20.86	20.76	20.83	20.80	20.49	21.03	20.50	21.36	20.50	21.01	20.63
Deep tillage	20.98	21.19	20.80	20.50	21.20	20.50	21.36	20.49	21.12	20.86	21.09	20.71
Mean	21.05	21.02	20.78	20.66	21.00	20.49	21.19	20.49	21.24	20.68		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											

In a column, Means sharing different letters statistically significant based on Tukey's HSD test ($p \leq 0.05$) NS = Non-significant, values in bracts presents 2018.

efficacy of different weed control methods in sunflower and concluded that different weed control practices had different efficacy rate and their effect was significant in controlling weeds. Our results are also comparable to those presented by Auskalniene et al. [41].

3.13.2 Fresh Weight (g m^{-2}) of Parthenium

Fresh weight of parthenium is affected significantly by tillage systems and different weed control practices. Interaction between main effects was also significant in both the experimental years. During first year of experiment (2017), statistically maximum fresh weight (652.33 g m^{-2}) of Parthenium was recorded in weedy check in combination with conventional tillage. During second experimental year, fresh weight (952.33 g m^{-2}) of Parthenium was recorded from weedy check × conventional tillage. All the treatments where weed control practices were applied produced significantly lower fresh weight of weeds. It shows that weed control practices are efficient in controlling parthenium (Tab. 7). These results are in line with the findings of Simic et al. [23] who stated that fresh weight of weeds was lower in experimental plots where weed control practices were applied but it had no concern with developmental stages of sunflower. Baskaran et al. [40] conducted an experiment to evaluate the performance of different weed control practices in sunflower. Lowest fresh weight of weeds was recorded where pre-emergence application of pendimethalin @ 1.0 kg ha^{-1} was combined with conventional tillage and hand hoeing after 40 days of sowing. Balasubramanian et al. [25] also mentioned similar results when they tested the performance of different pre and post emergence herbicides alone and in combination with different hand weeding in sunflower. Auskalniene et al. [41] compared the performance of minimum tillage, conservation tillage and mouldboard plough. They recorded minimum weed fresh weight in plots treated with mouldboard.

3.13.3 Dry Weight (g m^{-2}) of Parthenium

Dry weight of parthenium is affected significantly by tillage systems and different weed control practices in both years of study. Interaction between main effects was non-significant in both the experimental years. In

Table 7: Effect of tillage systems and different weed control practices on weed density (plants m-1), weed fresh and dry weight (g m-1) of sunflower in 2017 and 2018

Weed density (plants m-2)	Weedy check		Double hand hoeing		Sorghum straw mulch		Hoeing+ mulch		S-metolachlor		Mean	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Conventional tillage	50.33a	60.00a	4.00d	6.00d	12.66c	17.66c	3.66d	5.66d	12.00c	17.00c	16.53 A	21.26 A
Deep tillage	38.33b	48.33b	1.66d	3.66d	6.00cd	11.00cd	3.33d	4.00d	6.00cd	11.00cd	11.06 B	15.60 B
Mean	44.33A	54.16A	2.83C	4.83C	9.33B	14.33B	3.50C	4.83C	9.00B	14.00B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											
Weed fresh weight (g m-2)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	652.33 a	952.33 a	40.00 d	55.00 de	104.67 c	154.67 c	47.67 d	56.00 de	105.33 C	155.33 c	190.00 A	274.67 A
Deep tillage	492.67 B	792.67 b	17.67 d	32.67 e	60.00 cd	110.00 cd	21.00 d	32.00 e	61.00 Cd	111. 00 cd	130.47 B	215.67 B
Mean	572.50 A	872.50 A	28.83 C	43.83 C	82.33 B	132.33 B	34.33 C	44.00 C	83.17 B	133.17 B		
HSD	Tillage = NS (**NS**) Weed control practices = NS (**NS**) Interaction = NS (**NS**)											
Weed dry weight (g m-2)	**Weedy check**		**Double hand hoeing**		**Sorghum straw mulch**		**Hoeing+ mulch**		**S-metolachlor**		**Mean**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Conventional tillage	115.67	168.85	9.33	9.75	24.00	27.42	13.33	9.93	24.15	27.54	37.29 A	48.70 A
Deep tillage	93.33	140.54	3.33	5.79	12.00	19.50	5.67	5.67	12.33	19.68	25.33 B	38.23 B
Mean	104.50 A	154.70 A	6.33 C	7.77 C	18.00 B	23.46 B	9.50 BC	7.80 C	18.24 B	23.61 B		
HSD	Tillage = 138 (**132**) Weed control practices = 193 (**142**) Interaction = 386 (**NS**)											

In a column, Means sharing different letters statistically significant based on Tukey's HSD test ($p \leq 0.05$) NS = Non-significant, values in bracts presents 2018.

weed control practices, statistically highest weed dry weight (104.5 g m-2) was produced in weedy check. Next year, in weed control practices, statistically highest weed dry weight (154.7 g m-2) was produced in weedy check (Tab. 7). Plots treated with mouldboard plough produced lowest weed seed bank, weed fresh weight and weed dry weight in cereal crops and sunflower [41]. Parthenium's dry weight was lesser in all the weed control practices as compared to un-weeded check. It reflects that all weed control practices are efficient in controlling parthenium. These results agree with those of Beres et al. [39]. They evaluated the performance of different herbicides in sunflower and reported a decrease in dry weight of weeds by applying bifenox, flumioxazin and tribenuron-methyl as herbicide. Nadasy et al. [42] reported similar results. They further added the negative effects of herbicides on sunflower crop.

4 Conclusions

Results concluded that the double hand hoeing and hoeing plus sorghum mulch both in combination with deep tillage are the best weed control practices. These treatments give better weed control efficiency as compared to application of single dose of pre-emergence herbicide. Deep tillage with MB plough should be encouraged for better control of parthenium and higher yield of sunflower crop. Total dose of herbicide should be reduced by using hoeing and mulching in an integrated way. Parthenium should be controlled before crossing the critical range of competition, in order to get the higher yield of field crops. Ecology and biology of different biotypes of parthenium should be studied in different habitats. For controlling parthenium, efficacy of new herbicides in combination with cultural, physical and biological weed control methods should be explored.

Acknowledgement: I acknowledged to Higher Education Commission (HEC) Islamabad, Pakistan, for supporting me during PhD study.

Funding Statement: The author(s) received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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