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Integrated effect of soil tillage implements and weeding intervals on leaf area index and chlorophyll content of maize crop leaves

Luqman[1], and Zahid Hussain[1*]
[1]*Department of Weed Science, Faculty of Crop Protection Sciences, The University of Agriculture Peshawar, Peshawar*
**Corresponding author's email: zhussainws@aup.edu.pk*
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Abstract

The combination of tillage implements and weeding durations is very important for the improvement in the leaf area index and chlorophyll content of fodder maize along with the environment friendly management of the weeds infesting maize crop. In this connection, two field experiments were conducted at the Research Farm of the University of Agriculture Peshawar during the summer seasons of 2016 and 2017. Two tillage implements including mouldboard plough and cultivator as factor A (allotted to main plots) and 14 different weeding durations as factor B (assigned to subplots) were used in a randomized complete plot design with split plot arrangement. Data were recorded on leaf area, leaf area index, number of leaves plant-1, and the chlorophyll content of maize plants. The results indicated that there was a higher leaf area (294 cm2), leaf area index (2.1), leaves count plant-1 (11.7) and chlorophyll content (50.1 SPAD values) in mouldboard plough treatments than in the cultivator treatments. On the other hand, among the weeding intervals, the highest leaf area (377 cm2), leaf area index (2.7), leaves count plant-1 (13) and chlorophyll content (60.3 SPAD values) were achieved in full season weeding treatments, followed by 12 weeks weeding treatments, 10 weeks, 8, 6, 4 and 2 weeks weeding. Moreover, for the interaction of tillage implements and weeding regimes, the leaf area, leaf area index, leaves count plant-1and chlorophyll content were highest in the interaction of mouldboard plough under full season weeding regimes. In conclusion, the interaction of mouldboard plough with full season weeding has been the most successful combination for achieving the best leaf area index and chlorophyll content of maize crop plants.

Keywords: Chlorophyll content, LAI, maize, soil tillage implements, weeding intervals.

1. Introduction

Pakistan, as an agricultural country, is blessed with rich ecological diversity, that suit the growth of many globally cultivated crops including maize, the 3rd largest crop sown in Pakistan (FAO, 2019) and 2nd after wheat crop in the province of Khyber Pakhtunkhwa (Arif et al., 2011). Pakistan ranks 22nd among the global maize producing countries, where maize is cultivated on a total area of 1.35 million hectares, averaging 4852.7 kg yield ha-1 (FAO, 2019). The contribution of maize to the value addition is 2.7% in agriculture and 0.6% to GDP (GOP, 2019). Maize is grown in all the provinces of Pakistan for both grain and fodder purposes.

The interaction of weeds with maize has always been a core issue in Pakistan particularly since the local maize varieties are poor competitors with weeds infestation. Moreover, the weed competition effect on the leaf area, leaf area index (LAI) and chlorophyll content of maize crop has not been addressed properly in past. Therefore, the local varieties should be capable enough to compete with the infesting weeds. Maize though is a competitive crop; however, it cannot withstand the weed competition in the initial stages after germination.The associated weeds that emerge later in the crop season do not cause significant losses in maize (Usman et al., 2001). Tillage can play a key role in the management of weeds and indirectly in the improvement of crop performance (Li et al., 2021) especially in the soil chemical properties (Zhang et al., 2019). Shallow tillage is good for soil water conservation, but weed management becomes a problem in such a situation (Nakamoto et al., 2006). On the other hand, deep tillage is preferred for the reduction in the weed seed bank (Kaur and Arora, 2019). The selection of proper soil tillage operations is greatly dependent on the texture of the soil, type of cropsown,and conditionof the soil (Lovarelli et al., 2017).

Managing the weeds after the critical period of competition may result in more than 50% losses in maize crop (Usman *et al*., 2001). The losses can even be higher if the biomass of the infesting weeds; their density and species diversity are increased (Blackshaw *et al*., 2002). Weeds are therefore one of the key limiting factors in efficient maize crop production practices. Farkas (2006) mentioned that in case of the deterioration of the cultural conditions of the soil, the weeds start proliferation, and sometimes it gets very hard to control certain weed species with the help of the conventional methods of weeds management. Among the weeds of maize crop, the most harmful weeds that result in heavy losses include *Convolvulus arvensis* L., *Cynodon dactylon* L., *Cyperus rotundus* L., *Dactyloctenium aegyptium* L., *Digera arvense* L., *Digitaria sanguinalis* L., *Echinochloa crus-galli* L., *Portulaca oleracea* L., *Sorghum halepense* L., *Trianthema portulacastrum* L., and *Tribulus terrestris* L. (Saeed *et al*., 2013; Hadi *et al*., 2014; Inayat *et al*., 2014; Shah *et al*., 2014; Ullah *et al*., 2014).

Shaheen and Sabir (2017) noticed that improper tillage practices and timings result in poor soil tilth because of soil destruction. Also, the lower soil layers are compacted which adversely affects the germination and growth of the crop plants. Inamullah and Khan (2015) are of the view that proper care is needed in matching the different tillage practices with soil physical conditions for developing a logical approach. The different weeding durations were also studied in this instant research. Thus, the study was conducted to evaluate the individual effect of different tillage implements and weeding durations and their combined effect on the leaf related parameters of maize crop.

2. Material and methods

The experiment was conducted at the Research Farm of the University of Agriculture, Peshawar during the maize cropping seasons of 2016 and 17. The two trials were carried out on the same site in both years, with treatments re-randomized in the second year. The experimental site is situated at the geographical coordinates of 34.0151° N, and 71.5249° E. The maize variety 'Azam' was sown at the rate of 28 kg ha-1 and the recommended dose of nitrogen and phosphorus (120, 90 kg ha-1) were applied to the experiments. The K content measured before the experiment was sufficient in the soil. Half the dose of the nitrogen and full dose of phosphorus were applied at sowing time; while the remaining nitrogen was applied at the knee height stage of the crop growth. The fertilizer source for nitrogen was urea and that for phosphorus was single super phosphate. The experiments were irrigated six times during the whole maize crop seasons of both years (Ahmad et al., 2017).

The experimental units were of size 5m x 3m. Each unit plot comprised of five rows while each row was 5 m long, with 0.75 m distanceamong the adjacent rows. The experiments were laid out in RCBD with a split-plot arrangement having four replications. The tillage implements as factor A consisted of the cultivator and the mouldboard (MB) plough,wereassigned to the main plots of the experiment in each replication. The weeding intervals as factor B comprised of seven weed free and seven weed infested plots for certain uniform periods making a total of 14 treatments. In the weed free plots, the weeds were uprooted and removed for the first two weeks and then left infested for the rest of the season (W1), followed by plots where weeding was done for the first four weeks after sowing and then left without any weeding till crop harvesting (W2), the plots which were weeded out for the first six weeks were termed as W3, and so on. The control was termed W7which was kept weed free throughout the crop season during both the years of the research. Similarly, in weed infested periods the weeds were left undisturbed for certain periods reciprocal and parallel to the weed free plots. Thus, the weeds were left to grow freely for the first two weeks in W8 plots and then weeded out for the rest of the season; the weeds were left undisturbed for the first four weeks in W9 and then removed for the rest of the season. In the same way, the weeds were removed after the first six weeks of infestation in W10, and so on. The weeds were left undisturbed for the whole maize crop season in the W14 plots of the experiments, which was considered as the control treatment for the weed infested plots.

The data were recorded on leaf area, LAI, number of leaves plant-1 and chlorophyll content. The leaf area was measured in 10 selected plants. The length and width of all the leaves were measured with the help of a leaf area meter in cm2 in the lab of the Department of Weed Science. For LAI, the total leaf area of plants in one square meter area was measured and was divided by the total ground area covered by the measured plants. The number of leaves plant-1 was determined by counting the total leaves in the randomly selected 10 plants in each treatment and then means were computed. For the leaf chlorophyll content, SPAD-502 chlorophyll meter was used, manufactured by Konica Minolta (Japan), this device investigates the health of crops and soil through the measurement of chlorophyll content. So, in each experimental unit, ten plants were randomly selected; and from each selected plant, three mature leaves were randomly checked by the SPAD-502 plus chlorophyll meter. The reading was takenin three layers of each leaf i.e., bottom, mid and top. Finally, all the SPAD values measuredin the three layerswere averaged.

The data wasstatistically analyzed using the software Statistix 8.1 version for the ANOVA of Randomized Complete Block Design with the split-plot arrangement. The significance letters were generated using the LSD test after achieving significant F-test results. The individual effects were presented in tables while the interaction effects were graphically presented in bar graphs.

3. Result and discussion

3.1. Leaf area (cm2)

Leaf area is an important factor in the case of photosynthesis and yield of maize crop. A larger leaf area results in higher light interception and therefore has a greater effect on the crop yield. Analysis of variance revealed that both the tillage implements and weeding regimes had a significant ($P<0.05$) effect on the leaf area (Table-3.1).Combined two years of data for different tillage implements indicated that MB plough treatments showed a higher leaf area (294.5 cm2) as compared to the leaf area (286.1 cm2) observed in the cultivator treatments. The significant increase in leaf area is becauseMBplough can reduce the soil bulk density and improve soil aeration that allows the crop plants to utilize the available resources efficiently from the root zone during the initial growth stage (Bilalis and Karamanos, 2010; Javed et al., 2014). Among the different weeding intervals, the highest leaf area was seen in the full season weeding plots (377 cm2) followed by weeding for 12, 10, and 8 weeks (i.e. 354.9, 333.9, and 319.5 cm2, respectively). These experimental plots were free from weeds for longer periods which suppressed the growth of the weeds significantly. Leaves are the food manufacturing factories of plants and thus play a vital role in regulating plant growth and development. Similarly, any change in leaf area is an indicator hence yield of maize can be predicated based on its leaf area. Similar to our results, Mafongoya et al. (2006) and Hossein et al. (2014) achieved a higher leaf area of maize under different weeding durations. The weeds were rooted out from the field to minimize their competition with the crop. The availability of water, nutrients and air for maize plant growth ultimately expanded the crop leaf area. The leaf area was lowest (227.9 cm2) in the plots of no weed control throughout the growth period. Khatam et al. (2013) observeda lower leaf area due to a higher and longer infestation of weeds in the crop field. The higher weedinfestations clinch the nutrients, water, space and oxygen from the crop plants. As far as the interaction of tillage implements and weeding intervals is concerned, increasing the weeding intervals increased the leaf area in both the tillage implements as shown in Fig. 3.1. However, the leaf area was higher in MB plough than a cultivator. However, it is crystal clear that the leaf area was lowered by increasing the weeds infestation periods under both the tillage implements.

3.2. Leaf area index (LAI)

Leaf area is the ratio of the leaf area of a crop to the ground area upon which that crop stands. Data describing the LAI is presented in the Table 3.2. Statistical analysis of the averaged data disclosed that both the tillage implements and weeding intervals significantly ($P<0.05$) affected the LAI of the maize crop. The interaction effect between the tillage implements and weeding intervals was also significant however the remaining interactions were non-significant. The years' effect too as a source of variation was found non-significant (Table 3.2). The two years combined data analysis showed that a higher LAI (2.1) was recorded in the MB plough plots as compared to the LAI (2.0) in cultivator plots. The significant increase of LAI in MB plough operations is due to the disturbance of soil that usually can improve soil aeration, mineralization of organic nitrogen and its availability for plant consumption (Gul et al., 2011). Chhokar et al. (2007) and Minjian et al. (2007) are of the view that the use of MB plough vanishes the weeds from the crop field by decreasing the soil weed seed bank which indirectly affects the LAI of maize crop.

Table 3.1. Integrated effect of tillage implements and weeding intervals on leaf area (cm2) of maize crop during 2016 and 2017

	Year		Mean
Tillage Implements (TI)	2016	2017	
Cultivator	286.5	285.7	286.1 b
Mouldboard plough	289.5	299.6	294.5 a
$LSD_{(0.05)}$ for Tillage Implements			5.9
Weeding intervals (WI)			
(W1) Weeding for 2 weeks	278.3	285.3	281.8 ef
(W2) Weeding for 4 weeks	282.9	295.6	289.3 e
(W3) Weeding for 6 weeks	310.9	311.5	311.2 d
(W4) Weeding for 8 weeks	319.9	319.1	319.5 cd
(W5) Weeding for 10 weeks	336.4	331.4	333.9 c
(W6) Weeding for 12 weeks	343.5	366.3	354.9 b
(W7) Weeding for the full season	374.0	380.8	377.4 a
(W8) Infested for 2 weeks	270.1	279.5	274.8 efg
(W9) Infested for 4 weeks	266.5	277.0	271.8 efgh
(W10) Infested for 6 weeks	264.5	268.4	266.4 fgh
(W11) Infested for 8 weeks	254.3	262.3	258.3 ghi
(W12) Infested for 10 weeks	250.6	255.6	253.1 hi
(W13) Infested for 12 weeks	244.5	244.4	244.4ij
(W14) Infested for the full season	235.6	220.3	227.9 j
$LSD_{(0.05)}$ for weed intervals			19.6
Year means	288.0	292.7	NS
Interactions	Significance	Interactions	Significance
Year × TI	NS*	Year × WI	NS
TI×WI	27.7	Year ×TI×WI	NS

Means in the same column followed by the same letters are statistically similar at a 5 % level of significance.*NS = Non-significant

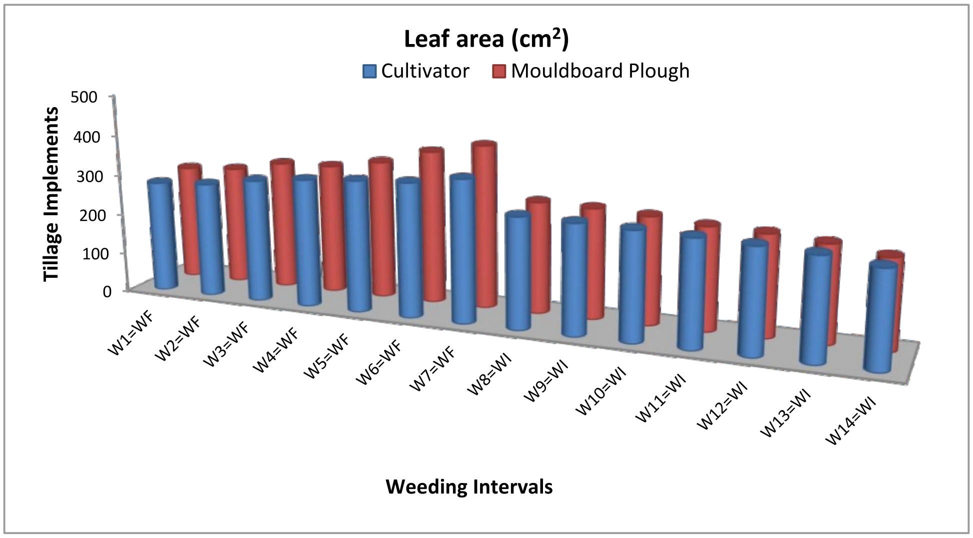

Fig. 3.1. Interaction of tillage implements and weeding intervals on leaf area (cm-2) (Standard error = 14.03). The intervals of weed free (WF) and weed infestation (WI) were explained in tables.

For weeding regimes, the means data indicated that higher LAI (2.7) was in the weed free plots for the whole cropping season, which was followed by plots of weeding for 12, 10 and 8 weeks (2.5, 2.4, and 2.3, respectively). This showed how much weed control is important for sustainable agriculture (Arif et al., 2013). However, the averaged values for infested periods resulted in lower LAI in the plots of no weed control for the entire crop season (1.6). The higher weed infestation is responsible for the lower LAI of maize (Dangwal et al., 2010). The interactions between various tillage implements and weeding intervals indicated that LAI increased with the gradual increase in the weeding periods under both tillage practices. Therefore, the higher weed infestation plots had lower LAI in treatments of both tillage implements (Fig. 3.2).

3.3. Number of leaves plant-1

Leaves are the platform of photosynthetic activities of crops through which crop biomasses are produced, then partitioned among various parts of the crops and finally stored for crop productivity. The data about number of leaves plant-1 presented in Tabel-3.3 revealed a significant ($P<0.05$) effect of tillage implements and weeding intervalson the number of leaves plant-1; while the interactions were non-significant. A combined analysis of variance for tillage implements showed that the number of leaves plant-1 (11.7) was higher in the treatments of tillage with MB plough than in the cultivator (10.5) (Ashare et al., 2011). However, MB plough efficiently breaks the soil clods, allows the free movement of air and water, removes weeds and provide a better environment for increasing the number of leaves of maize plants. Among the weeding regimes for weed free periods, the highest number of leaves (13 plant-1) was obtained in the full season weed free plots, followed by weeding for 12 weeks (12.6 plant-1), 10 weeks (12.3 plant-1), 8 weeks (11.9 plant-1) and 6 weeks (11.6 plant-1). However, weeds compete with the crop for food, water, air, light and space while in the control plots there was no weed for competition with crop and achieved the maximum number of leaves. It is because weeds were controlled in full weedy plots as compared to fully infested plots. The crop plants availed the nutrients, light and moisture and got a maximum number of leaves plant-1 in the full season weed free treatments. On the other hand, for the infested plots, the valuefor the number of leaves plant-1 was minimum in the plots of full season infested (10.3), followed by infested plots for 12, 10, 8 and 6 weeks (10.8, 10.9, 11.0, and 11.2 leaves plant-1, respectively). Looking at the interaction effect of tillage implements and weeding intervals, the highest number of leaves plant-1 was observed in the highest weeding periods under the MB plough treatments while the lowest number of leaves plant-1was noticed in the longest intervals of weed infestation.The Fig. 3.3 graphically presents significant interaction results.

Table 3.2. Integrated effect of tillage implements and weeding intervals on LAI of maize during 2016 and 2017

Tillage Implements (TI)	Year 2016	Year 2017	Mean
Cultivator	1.9	2.1	2.0 a
Mouldboard plough	2.2	2.1	2.1 a
$LSD_{(0.05)}$ for TD			0.1
Weeding intervals (WI)			
(W1) Weeding for 2 weeks	2.0	2.0	2.0 ef
(W2) Weeding for 4 weeks	2.1	2.1	2.1 de
(W3) Weeding for 6 weeks	2.4	2.1	2.3 cd
(W4) Weeding for 8 weeks	2.3	2.2	2.3 cd
(W5) Weeding for 10 weeks	2.4	2.4	2.4 bc
(W6) Weeding for 12 weeks	2.6	2.5	2.5 ab
(W7) Weeding for the full season	2.8	2.7	2.7 a
(W8) Infested for 2 weeks	1.9	2.2	2.1 de
(W9) Infested for 4 weeks	1.8	2.1	2.0 ef
(W10) Infested for 6 weeks	1.7	2.1	1.9 efg
(W11) Infested for 8 weeks	1.6	1.9	1.8 fgh
(W12) Infested for 10 weeks	1.8	1.8	1.8 fg
(W13) Infested for 12 weeks	1.7	1.7	1.7 gh
(W14) Infested for full season	1.6	1.6	1.6 h
$LSD_{(0.05)}$ for WI			0.2
Year means	2.0	2.1	NS*
Interactions	Significance	Interactions	Significance
Y × TI	NS	Y × WI	NS
T × WI	0.3	Y × TI x WI	NS

Means in the same column followed by the same letters are statistically similar at a 5 % level of significance.*NS = Non Significant

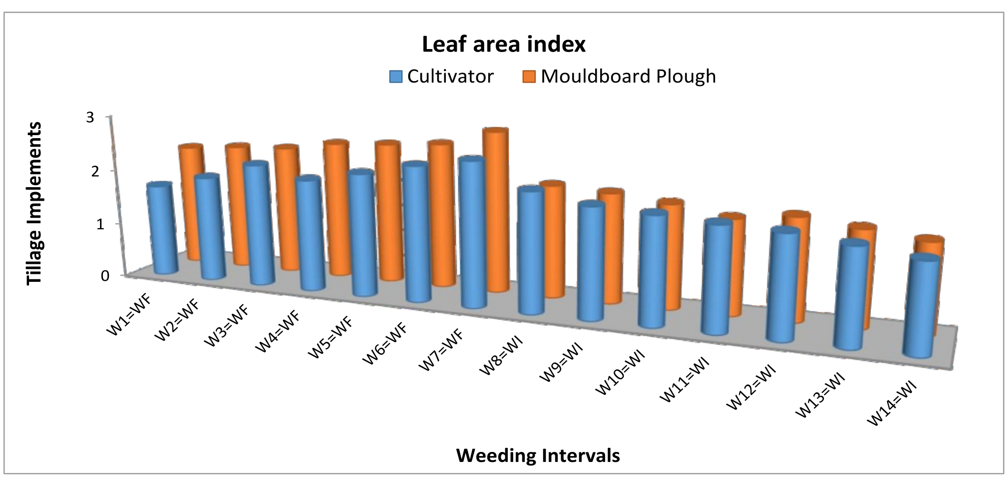

Fig. 3.2. Interaction of tillage depths and weeding regimes on leaf area index (Standard error = 0.16). The intervals of weed free (WF) and weed infestation (WI) were explained in tables.

Table 3.2. Integrated effect of tillage implements and weeding intervals on LAI of maize during 2016 and 2017

	Year		
Tillage Implements (TI)	2016	2017	Mean
Cultivator	10.6	11.9	10.5 b
Mouldboard plough	11.3	12.1	11.7 a
$LSD_{(0.05)}$ for TD			NS
Weeding intervals (WI)			
(W1) Weeding for 2 weeks	10.8	11.1	11.0 gh
(W2) Weeding for 4 weeks	11.0	11.7	11.3 efg
(W3) Weeding for 6 weeks	11.3	12.0	11.6 de
(W4) Weeding for 8 weeks	11.7	12.2	11.9 cd
(W5) Weeding for 10 weeks	12.1	12.6	12.3 bc
(W6) Weeding for 12 weeks	12.3	13.0	12.6 ab
(W7) Weeding for the full season	12.8	13.2	13.0 a
(W8) Infested for 2 weeks	10.6	12.4	11.5 def
(W9) Infested for 4 weeks	10.4	12.1	11.3 efgh
(W10) Infested for 6 weeks	10.3	12.0	11.2 fgh
(W11) Infested for 8 weeks	10.1	11.9	11.0 gh
(W12) Infested for 10 weeks	10.1	11.8	10.9 gh
(W13) Infested for 12 weeks	10.1	11.6	10.8 h
(W14) Infested for full season	9.8	10.7	10.3 i
$LSD_{(0.05)}$ for WI			0.5
Year means	11.0	12.0	NS*
Interactions	Significance	Interactions	Significance
Y × TI	NS	Y × WI	0.6
TI × WI	0.6	Y × TI× WI	NS

Means in the same column followed by the same letters are statistically similar at a 5 % level of significance.*NS = Non Significant

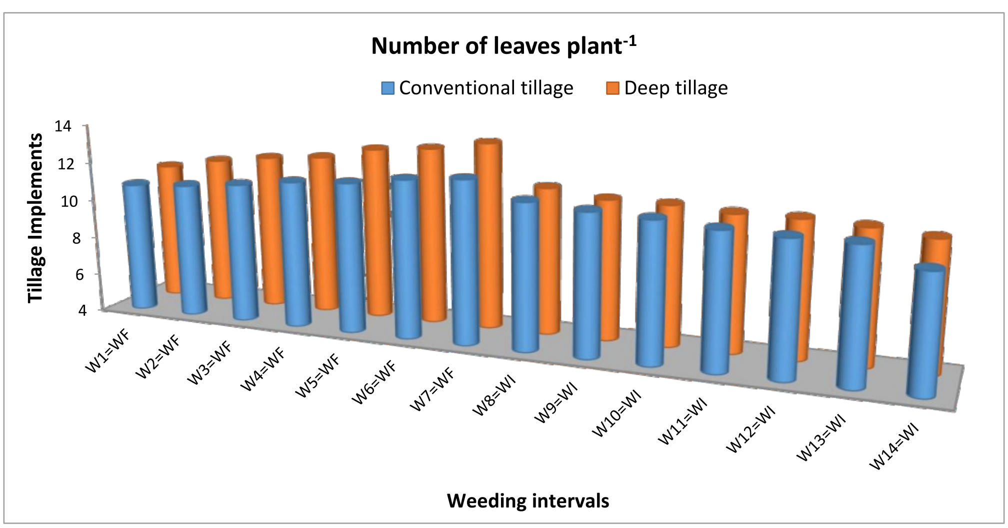

Fig. 3.3. Interaction of tillage depths and weeding regimes on number of leaves plant-1 (Standard error = 1.97). The intervals of weed free (WF) and weed infestation (WI) were explained in tables

3.4. Leaf chlorophyll content

The analysis of variance showed that various tillage implements and weeding intervals significantly ($P<0.05$) affected the chlorophyll content of maize crop leaves (Table 3.4); while the interactions (year x tillage implements and year × tillage implements × weeding intervals) were found non-significant for chlorophyll content. Moreover, the year effect used as a source of variations in the combined analysis was also non-significant. The perusal of data in Table 3.4 exhibited that chlorophyll content was higher (50 SPAD values) in MB plough plots as compared to the plots operated with a cultivator (49 SPAD values). Similarly, MB plough not only preserved soil moisture and insured better crop growth but also disturbedthe weeds seed bank as the weeds seeds could not germinate upon their exposure to sunlight or due to the deep burialof the seeds (Ali et al., 2012). The increase of chlorophyll content might be due to the well-aerated soils, favorable soil moisture and nutrient uptake.

Table 3.4. Integrated effects of tillage depths and weeding regimes on leaf chlorophyll content in maize during 2016 and 2017

	Year		
Tillage Implements (TI)	2016	2017	Mean
Cultivator	50.2	47.7	49.0 a
Mouldboard plough	50.5	49.7	50.1 a
$LSD_{(0.05)}$ for TD			1.0
Weeding intervals (WI)			
(W1) Weeding for 2 weeks	50.6	48.5	49.5 a
(W2) Weeding for 4 weeks	50.3	47.5	48.9 c
(W3) Weeding for 6 weeks	53.2	52.3	52.8 b
(W4) Weeding for 8 weeks	55.0	52.7	53.9 b
(W5) Weeding for 10 weeks	57.7	53.0	55.3 b
(W6) Weeding for 12 weeks	61.0	55.8	58.4 a
(W7) Weeding for the full season	63.1	57.6	60.3 a
(W8) Infested for 2 weeks	48.8	49.1	48.9 c
(W9) Infested for 4 weeks	45.6	45.4	45.5 de
(W10) Infested for 6 weeks	46.0	45.1	45.5 de
(W11) Infested for 8 weeks	44.0	47.6	45.8 d
(W12) Infested for 10 weeks	43.6	45.1	44.4 de
(W13) Infested for 12 weeks	44.5	41.7	43.1 ef
(W14) Infested for full season	41.8	40.9	41.4 e
$LSD_{(0.05)}$ for WI			2.6
Year means	50.4	48.7	NS
Interactions	Significance	Interactions	Significance
Y × TI	NS*	Y × WI	3.7
TI × WI	3.7	Y × TI x WI	NS

Means in the same column followed by the same letters are statistically similar at a 5 % level of significance. *NS = Non Significant

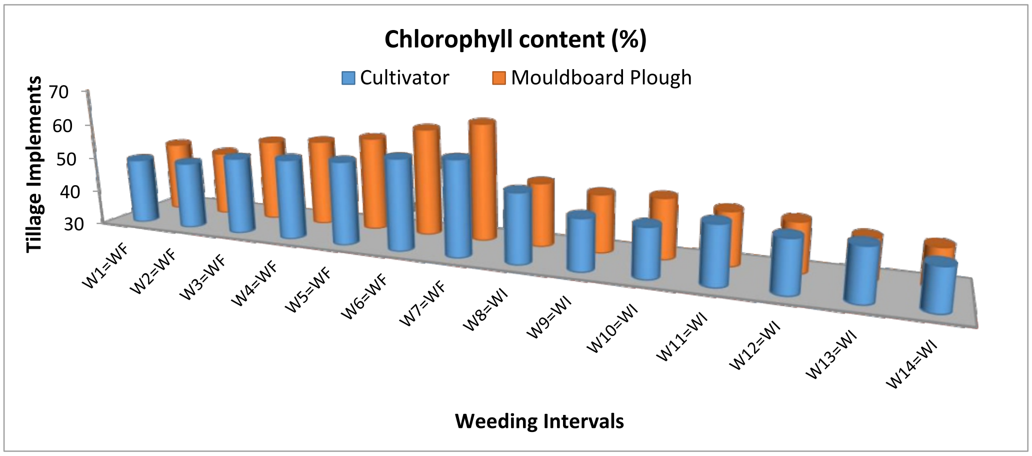

Figure-3.4. Interaction of tillage implements and weeding intervals on leaf chlorophyll content (Standard error = 2.94).

From the combined averaged data of the two years indicated in Table 3.4 for weeding intervals that chlorophyll content was highest (60.3) in treatments where weeds were removed throughout the crop growingseason, followed by treatments where weeding was done for 12, 10, 8 and 6 weeks (58.4, 55.3, 53.9 and 52.8, respectively). The significant increase of chlorophyll content in different weeding plots might be due to the absence of weeds resulting in minimum competition from the weeds with the crop plants. The lowest chlorophyll content (41.4) was found in treatments infested with weeds for the full season.

The interaction effect for tillage levels and weeding regimes exhibited the highest chlorophyll content in MB plough plots where weeding was conducted throughout the crop season (Fig. 3.4). The lowest value for chlorophyll content was achieved in cultivator treatments where weeds were left free to grow, for 12 weeks.

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Compliance with ethical standards

The authors declared no conflict ofinterest in the respective research work. The first author is the Ph.D. scholar and the second is the major supervisor.

Author's contribution

Luqman planned and conducted the research. He also collected and analyzed the field data, did provision of relevant literature, and wrote the manuscript. Zahid Hussain supervised the research, had a technical review and proof reading of the manuscript before submission.

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