Research Article

Influence of Herbicides on Weeds and Wheat (*Triticum aestivum*) Dynamics under Stale Seedbed

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Abstract | An experiment was conducted at the Research Farm of the Muhammad Nawaz Shareef University of Agriculture, Multan during the winter season of 2018-19 with the objective to evaluate weed dynamics, growth, and productivity of wheat crop under stale seedbed. This experiment was held under RCBD with three replications. The study consisted of eight treatments viz: T_1: stale seedbed + no herbicide, T_2: stale seedbed + glyphosate @ 711 a.i mL ha^{-1}, T_3: stale seedbed + paraquat-dichloride @ 494 a.i mL ha^{-1}, T_4: stale seedbed + atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i g ha^{-1}, T_5: stale seedbed + glyphosate @ 356 a.i mL ha^{-1} + paraquat @ 247 a.i mL ha^{-1}, T_6: stale seedbed + glyphosate @ 356 a.i mL ha^{-1} + atlantis @ 7.5 a.i g ha^{-1}, T_7: stale seedbed + paraquat @ 247 a.i mL ha^{-1} + atlantis @ 7.5 a.i g ha^{-1}, T_8: stale seedbed + glyphosate @ 237 a.i mL ha^{-1} + paraquat @ 165 a.i mL ha^{-1}+ atlantis @ 5 a.i g ha^{-1}. The highest WCE (84%), HEI (13.01), P_n (13.83 µmol CO_2 m^{-2} s^{-1}) and g_s (234.33 mmol m^{-2} s^{-1}) was recorded in plots treated with glyphosate + paraquat + atlantis. The highest NAR (3.60 gm^{-2}day^{-1}), LAI (4.82), GCR (7.87 gm^{-2}day^{-1}), LAD (186.43 days) was recorded in the treatment Stale seedbed + glyphosate + paraquat + atlantis. This treatment depicted the highest productive tillers m^{-2} (246.33), grains spike^{-1} (53.67), 100-grains weight (31.88 g), and grain yield 40% (4.65 Tons ha^{-1}) in comparison with the no herbicide treated plots. From this study, it is concluded that using the stale seedbed, pre- and post-emergence herbicides in reduced doses can restrict weeds growth till 40 DAS to maximize wheat productivity.

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Introduction

Weeds infestation is a major threat to improving crop growth and productivity (Mishra *et al.*, 2016). It has the potential to limit crop growth and development (Cathcart and Swanton, 2004), which resulted in wheat yield reduction of up to 46 % (Khan and Haq, 2002) and 73.2% (Tesfay, 2014). The potential reduction of grain yield usually depends on the type and density of weeds and the duration of interference (Zimdahl, 2018).

In Pakistan, wheat fields are mostly infested with 45 weed species in various growing areas (Qureshi and Bhatti, 2001). Major weeds infesting the wheat crops in Pakistan include *Avena fatua*, *Chenopodium album*, *Convolvulus arvensis*, *Cynodon dactylon*, *Malva parviflora*, *Melilotus indica*, *Medicago denticulata*, *Phalaris minor* and *Rumex dentatus* (Marwat *et al*., 2013). Weeds interfere with crop plants for resources which essential for growth like water, nutrients, light and space (Bibi *et al*., 2008). Under intensive farming system various methods were used to limit weeds under economic thresh hold level. Usually, farmers use non-chemical method to control weeds i.e., stale seedbeds (Abouziena and Haggag, 2016). While chemical control most effective and most economic method to control weeds (Amare *et al*., 2016).

In modern world different techniques are used to manage the weeds density (Kahramanoglu and Uygur, 2010). Farmers have historically used a different non-chemical weed management method, including as crop rotation, cover crops, tillage, stale seedbeds, etc. (Abouziena and Haggag, 2016). Now days h erbicides are frequently used to control weeds (Sindhu *et al*., 2010). Anyhow, the improper use of herbicides led to some environmental risks, such as weeds resistance (Sindhu *et al*., 2010). An integrated strategy to management the weeds can offer long-lasting and environmentally safe weed control (Harker and O'Donovan, 2013). Herbicide is a supplementary strategy used in combination with other non-chemical approaches in the integrated weed management (IWM) approach. This clearly shows that non-chemical weed management strategies are necessary to implement IWM (Harker and O'Donovan, 2013). Before sowing, stale seedbed creation is efficiently managed weed density during the early crop season for both narrow and broadleaved species (Sindhu *et al*., 2010). Although perennial weeds are effectively controlled, pre-sown tillage activities are the most effective method (Brandsaeter *et al*., 2017).

The weeds density is a leading limiting factor for the productivity of wheat in the world. At the same time, the world population is rapidly growing day by day. Hence, a more comprehensive and sustainable weed control method is necessary for economical wheat production. Moreover, weeds control by using single method usually does not give socially and economically acceptable outcomes. Therefore, an integrated weed management approaches are necessary to control the number of weeds under variable environments. To ensure food security it is essential to enhance wheat crop growth and development, which will, resulted to higher crop productive. This could be achieved by using of stale seedbed technology to control the weed seed bank with the integration of pre-emergence and post-emergence herbicide to control the weeds for longer period. This idea has not been documented yet. Hence, this study has been set to explore the impact of stale seedbed on the wheat crop physiology, growth, and yield performance of wheat. The outcomes of this study will help in developing the most efficient weed control strategy which may ultimately reduce the weed seed bank of the wheat growing areas in Pakistan.

Materials and Methods

The present study was conducted at the Research farm of Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan. The study area is situated in the arid region of southern Punjab at 30 N latitude and 71 E longitude, at an elevation of 122 m above mean sea level. The dry environment of Multan features cold winters and hot summers. The temperature reaches a maximum of 49 °C in the summer and a minimum of 1 °C in the winter (Majid *et al*., 2020). Crop season weather data of maximum and minimum temperature (T), sunshine hours, and rainfall were taken from the Agro-metrological Cell, Department of Agronomy, Muhammad Nawaz Shareef University of Agriculture, Multan (Figures 1, 2). The soil type of the site is saline Indus plain Haplic Yermosol (FAO-UNESCO, 1977). The study consisted of eight treatments which were arranged under a randomized complete block design (RCBD) Table 1.

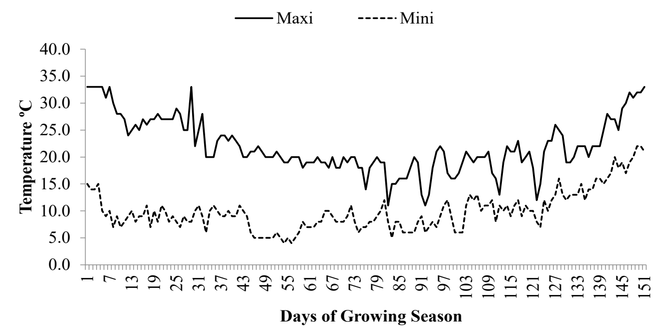

Figure 1: *Temperature during the crop period (2018-19).*

Table 1: *Treatments used in present study.*

S. No	Treatments	Dose (a.i)
i	Stale seedbed + no herbicide	-
ii	Stale seedbed +glyphosate	711 a.i $mLha^{-1}$
iii	Stale seedbed + paraquat-dichloride	494 a.i $mLha^{-1}$
iv	Stale seedbed + atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium)	15 a.i gha^{-1}
v	Stale seedbed + glyphosate + paraquat	356 a.i $mLha^{-1}$+247 a.i $mLha^{-1}$
vi	Stale seedbed + glyphosate + atlantis	356 a.i mLha-1+7.5 a.i gha^{-1}
vii	Stale seedbed + paraquat + atlantis	247 a.i $mLha^{-1}$+7.5 a.i gha^{-1}
viii	Stale seedbed + glyphosate + paraquat + atlantis	237 a.i $mLha^{-1}$+165 a.i $mLha^{-1}$+ 5 a.i gha^{-1}

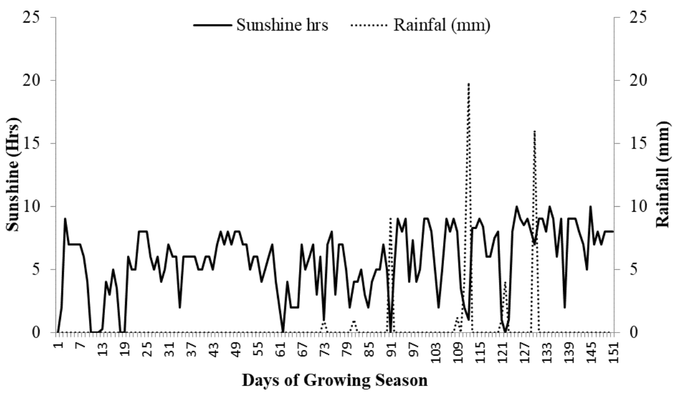

Figure 2: *Rainfall and Solar radiation during the crop period.*

For the creation of a stale seedbed, a pre-sown tillage operation was done in the 2nd week of November 2018 after that experimental site was irrigated with canal irrigation water to encourage weeds. When weeds emerged in the field, glyphosate (broad-spectrum herbicide) and paraquat-dichloride (broadleaf herbicide) were applied as pre-emergence herbicides to control weeds interference at the germination stage during 1st week of December 2018. Afterward, a seedbed was prepared for the sowing of wheat (*Triticum aestivum*). Moreover, at 35 DAS Atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) was applied as post-emergence herbicide to check the grassy and broadleaf weeds that germinated after first irrigation (Table 1). On the basis of gross plot area water and herbicide, the quantity was determined. Weedy check (stale seedbed + no herbicide) plot remained infested with native weed population during the whole growing season. During this whole study wheat crop took 4 times irrigation excluding irrigation for seedbed preparation and rain outbreaks and the crop was harvested during the first week of April 2019. Weed parameters i.e., Weed control efficiency (WCE) and weed persistence index (WPI) were recorded at 30 and 40 DAS and the herbicide efficiency index (HEI) recorded was determined at the harvest of a crop.

WCE, WPI, and HEI were determined based on the calculated data of weeds m-2 by using the following formulas:

$$\text{WCE (\%)} = \frac{WPC - WPT}{WPC} \times 100$$

Where WPC= weed population m^{-2} in control treatment; WPT= weed population m^{-2} in specific treatment.

$$\text{HEI} = \frac{\frac{YT - YC}{YC} \times 100}{\frac{DMT}{DMC} \times 100}$$

Where YT= Yield from treated plots; YC= Yield from the control plot; DMT= Dry matter of weeds in specific treatment; DMC= Dry matter of weeds in the control treatment.

WPI was determined through the following formula:

$$\text{WPI} = \times \frac{\text{Dry matter of weeds in control plot}}{\text{Weed count in treated plot}}$$

Physiological parameters (stomatal conductance mmol m^{-2} s^{-1}, sub stomatal conductance mmol m^{-2} s^{-1} and net photosynthetic rate µmol CO_2 m^{-2} s^{-1}) were recorded by using CIRUS- 3 Portable Photosynthesis System by PP System 110 Haverhill Road, suite 301 amesbury, MA 01913, after 7 days of herbicide application. All growth parameters samples were collected from 30 cm area of each experimental plot with 15 days interval. Five-gram sub-sample was collected from each sample. Leaf area (LA) was determined by using the digital leaf area meter and LAI was determined by taking the leaf area (LA) to land area (LA) ratio.

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$$LAI = \frac{Leaf\ area}{Land\ Area}$$

LAD was determined on the basis of fortnight LAI data of by the following equation (Beadle, 1987).

$$LAD = (LAI_2 + LAI_1) \times (t_2 - t_1)/2$$

Where: LAI_1= At 1st harvesting LAI; LAI_2= At 2nd harvesting LAI; t_1= 1st sample harvesting time; t_2= 2nd sample harvesting time.

CGR was derived from the fortnightly data by using given equation (Hunt, 1979).

$$CGR = \frac{(W_2 - W_1)}{(t_2 - t_1)}$$

Where, W_1 = Constant dried weight of 1st sample; W_2 = Constant dried weight of 2nd sample; t_1= 1st sample harvesting time; t_2= 2nd sample harvesting time.

NAR was derived from the given formula (Beadle, 1987).

$$NAR = \frac{(Total\ dry\ matter)}{(Leaf\ area\ duration)}$$

Where; TDM= TDM (W_2-W_1);

$$LAD = (LAI_2 + LAI_1) \times (t_2 - t_1)/2$$

Chlorophyll content was determined by using the chlorophyll meter Minolta SPAD-502 by Konica Minolta Sensing Singapore Pte LTD. Data was collected by selecting three random plant's tips, center and base and yield and yield parameters were recorded at the harvest of crop.

All parameters of recorded data were analyzed by the statistical technique of Fisher's analysis of variance by using the Statistix 8.1 by Analytical Software, 2105 Miller Landing Rd Tallahassee, FL, 32312. All treatment means were tested with 5% probability level (Steel *et al*., 1997).

Results and Discussion

Weeds control efficiency (WCE %)

The number of weeds reduced as a result of weed control treatment is known as weed control efficiency (WCE) (Mani *et al*., 1973). WCE was significantly affected by the different herbicides which were used

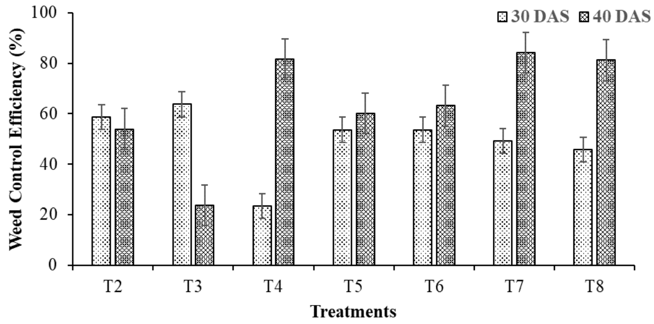

Figure 3: *WCE as affected by application of herbicide.*
T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.Means sharing same alphabets do not differ significantly by using HSD test at alpha 0.05

as sole or in reduced combination in the present study. WCE of pre- and post-planting herbicides as affected by stale seedbed has been shown in Figure 3. At the earlier crop growth stages, weeds are the main factor that interferes with a crop which increases the importance of weed management at earlier stages. Among the various herbicide treatments, the highest WCE was observed under stale seedbed + paraquat + atlantis followed by stale seedbed + atlantis treatment at 40 DAS. The highest WCE (84%) was observed where pre and post-emergence herbicides were applied and while in the plot treated with pre-emergence herbicide observed the lowest WCE (23%) was at 40 DAS. The likely reason might be the prolonged growing season, which favored subsequent weed flushes to appear and establish in a better way. The highest weed control efficiency in stale seedbed + atlantis and stale seedbed + paraquat + atlantis was due to the application of post-emergence herbicide. While in a plot having stale seedbed + paraquat where post-emergence herbicide was not applied and pre-planting herbicide paraquat residue deteriorated due to this weed found the favorable condition to grow in this treatment. This clearly indicates the importance of post-emergence herbicides. Because treatment stale seedbed + paraquat + atlantis and stale seedbed + glyphosate + paraquat + atlantis are the treatments where pre-plant herbicides were followed with post-plant herbicide this might be the reason for the highest WCE in this treatment. In these treatments, combined application of pre-plant and post-plant herbicides provides a suitable environment for wheat crop plants upon growing season this also restricts weeds at lateral growing stages of wheat crop. While in stale seedbed + glyphosate and stale seedbed + paraquat treatment only pre-planting herbicide were applied. These herbicides only efficiently control the weeds at early crop stages after that, in these treatment weeds obtained favorable conditions and interfere with wheat crop. Outcomes of this study showed similarity with results of Teja *et al.* (2016) and Kumar *et al.* (2017) who revealed that combined application of herbicide decreases the density of the weeds which ultimately increases weed control efficiency.

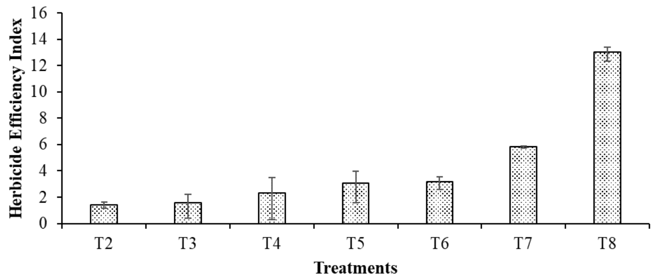

Figure 4: *HEI as influenced by application of herbicide.*
T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.

Herbicide efficiency index (HEI)

The herbicide efficiency index (HEI) shows how effective a specific herbicide is at both weed control and crop toxicity (Krishnamurthy *et al*., 1975). HEI was determined to measure the effectiveness of herbicide doses to manage weeds. The herbicide efficiency index of pre-and post-emergence herbicides as affected by stale seedbeds were shown in Figure 4. The highest value of HEI (13.01) was recorded in stale seedbed + glyphosate + paraquat + Atlantis. While on other hand, the lowest HEI (1.44) was found in the plot treated with stale seedbed + glyphosate. Which was followed by stale seedbed + paraquat and stale seedbed + atlantis. Here presented data showed the highest HEI observed in treatments where integrated herbicides were used in reduced doses which significantly controlled weeds density throughout the crop growing season and improved the HEI. The outcomes of this study showed similarity with the results of Hakoomat *et al.* (2017) who stated that pre- and post-herbicide uses significantly reduced weed density. Moreover, the results of the study depicted that herbicide application improved HEI.

Weed persistent index (WPI)

A low level of WPI is very essential for the efficient control of the weeds. The weed persistence index can be used to find the herbicide efficacy to manage weeds. The weed persistence index of pre- and post-planting herbicides as affected by stale seedbed technology are shown in Figure 5. At 30 DAS, WPI was the highest (0.093) in stale seedbed + glyphosate during 40 DAS while, on the other hand, the minimum value of WPI (0.010) was found in stale seedbed + glyphosate + paraquat at 30 DAS. Upon the period of 30 DAS, lower WPI was observed in all treatments could be due to the presence of herbicides' residual effects. This could be the reason for the low WPI in the experiment. Here all experimental plots where sole pre-emergence herbicides were applied showed higher WPI which revealed that herbicides residues deteriorate. Resulted in lower herbicide restrictions were recorded which increase the interference of weeds. The results of this study showed that over time increase in WPI which indicate that herbicides efficacy was reduced. This study results showed that better weed control strategy significantly reduces the weeds density and improved the WPI. Furthermore, data presented that combined use of herbicide (prior and after sowing) restricted the density of the weeds more efficiently as well as also reduced assimilation of dry matter by weeds improving the WPI for a longer period of crop growing season. This result produced similar results to Khaliq *et al.* (2011) who stated that treatment with low WPI showed good growth and development than the rest of the untreated (no herbicide used) treatments.

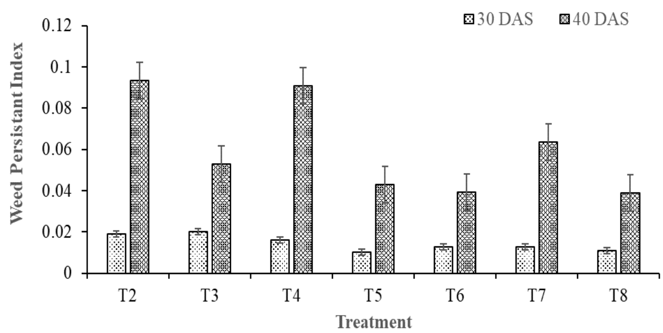

Figure 5: *WPI as affected by application of herbicide.*
T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.

Substomatal conductivity (Ci mmol m^{-2} s^{-1})

Sub stomatal conductance is the CO_2 absorption and conductance through moist mesophyll cell walls. The majority of the water vapors leaving the substomatal cavity are diffused CO_2 that is diffused even further into the intercellular air gaps of the leaf mesophyll (Pallardy, 2008). A statistically significant difference was recorded among treatments. Data regarding *Ci* (mmol m^{-2} s^{-1}) are shown in Figure 6. The highest (305.33-mmol m^{-2} s^{-1}) *Ci* was recorded in stale seedbed + no herbicide which was statistically similar with treatment stale seedbed + glyphosate + paraquat + atlantis whereas, the lowest *Ci* (264.33 mmol m^{-2} s^{-1}) was recorded in stale seedbed + atlantis. This could be due to the use of a recommended dose of atlantis. Contrarily, the plot where stale seedbed + no herbicide and in stale seedbed + Glyphosate + Paraquat + Atlantis reduced dose of post-emergence herbicide was applied that helps the crop to avoid phytotoxicity. The next highest (289 mmol m^{-2} s^{-1}) *Ci* was recorded in stale seedbed + paraquat + atlantis which was at par with stale seedbed + glyphosate + paraquat. Results showed that herbicides use to put a significant influence on sub stomatal conductance of wheat. This could be due to phytotoxicity. A decrease in the sub-stomatal conductance put a substantial effect on the photosynthetic process of the crop. These results are supported by the study of Langaro *et al*. (2016) stating that herbicidal toxicity restricted the rate of physiological processes, which ultimately cost the plant by a reduction in the photosynthetic activities.

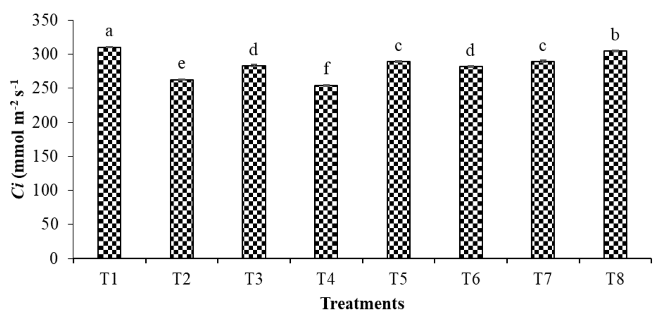

Figure 6: *Effect of herbicide on Ci of wheat crop. HSD Tukey's$_{0.05}$= 4.93*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.Means with different letters are statistically significantly different by using at HSD α 0.05.

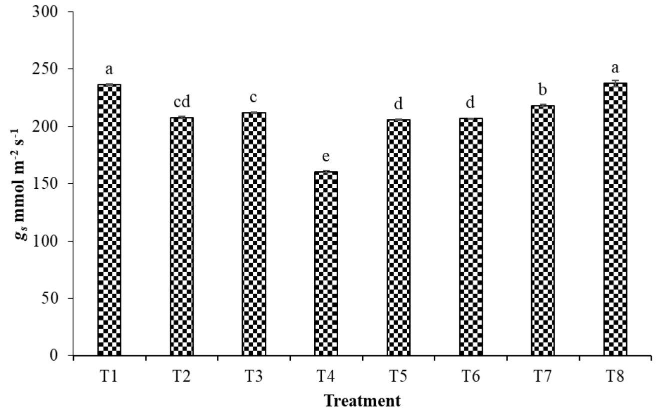

Figure 7: *Effect of herbicide use on g_s of wheat crop. HSD Tukey's$_{0.05}$= 4.93*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.Means with different letters are statistically significantly different by using at HSD α 0.05.

Stomatal conductance (g_s mmol m^{-2} s^{-1})

Gas diffusion through a plant's stomata, including carbon dioxide, water vapor, and oxygen, is known as stomatal conductance (gs). In response to environmental conditions, it also acts as a gauge for stomatal opening (Hunt *et al*., 2017). Data related to stomatal conductance are shown in Figure 7. There was a significant difference noticed among various treatments. Highest (236.33 mmol m^{-2} s^{-1}) g_s was recorded in a plot with no herbicide whereas, the lowest (160.33 mmol m^{-2} s^{-1}) stomatal conductance was recorded in a plot with a full dose of post-emergence herbicide was used. This could be attributed to the application of atlantis in plot stale seedbed + atlantis which partially restricted the activities of stomatal conduction of plant leaf. Contrarily, in stale seedbed + no herbicide not a single herbicide was applied that helps the crop to avoid phytotoxicity and continue their physiological processes. In reduced doses highest (234.33 mmol m^{-2} s^{-1}) stomatal conductance was recorded in stale seedbed + glyphosate + paraquat + atlantis which was followed by the plot treated with stale seedbed + paraquat + atlantis that showed (218 mmol m^{-2} s^{-1}) rate of stomatal activity. The outcomes of this experiment showed that herbicide application significantly influenced stomatal conductance. The likely reason might be the use of post-emergence herbicides causes strong phytotoxicity which restricted the stomata conductance rate and chlorophyll contents of plants. Due to the reduction of these basic components net photosynthetic rates are also negatively influenced (Langaro *et al*., 2016). Minimum stomatal conductance stale seedbed + atlantis was due to the application of post-emergence herbicide. While control treatment where no herbicide was used crop plants found favorable conditions to grow. Experimental results are in line with Langaro *et al*. (2016) who revealed that herbicide application influenced the stomatal conductance significantly.

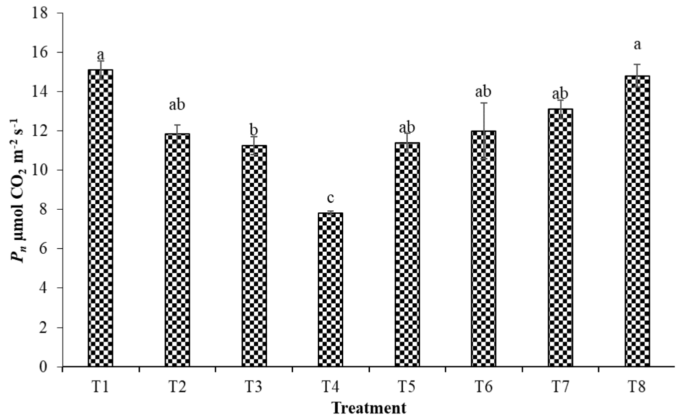

Figure 8: *Effect of herbicide use on net photosynthetic rate of wheat crop. HSD Tukey's $_{0.05}$= 3.37*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}. Means with different letters are statistically significantly different by using at HSD α 0.05.

Net-photosynthetic rate (P_n µmol CO_2 m^{-2} s^{-1})

The net photosynthetic rate (*Pn*) is a measure of how well different plants are able to store energy and organic matter (Zhang *et al*., 2020). Net-photosynthetic rate *(P_n)* was recorded after the application of herbicides. Data related P_n rates are shown in Figure 8. There is a significant difference observed among treatments as highest (15.1 µmol CO_2 m^{-2} s^{-1}) P_n was recorded in stale seedbed + no herbicide which was statistically at par with treatment stale seedbed + glyphosate + paraquat + atlantis. Whereas, lowest P_n (7.82 µmol CO_2 m^{-2} s^{-1}) was recorded in stale seedbed + atlantis. While in plots treated with reduced doses showed highest P_n (13.83 µmol CO_2 m^{-2} s^{-1}) in stale seedbed + paraquat + atlantis which was at par with rest of treatments stale seedbed + glyphosate; stale seedbed + glyphosate + paraquat and stale seedbed + glyphosate + atlantis. Results of this study showed substantial low P_n in stale seedbed + atlantis plot that could be due to post emergence herbicide application. While in the same time in control treatment and plot with pre-emergence herbicides and reduce dose herbicide treated plot showed normal growth and development. Presented data showed better response of crop physiological processes but where post-emergence herbicide was applied to control weeds. It restricts the all physiological processes particularly P_n. Because any kind of stress to plants physiological processes directly influence the assimilation rate of CO_2. So, P_n also affected significantly. Similar results were also reported by Javaid (2010) who stated that herbicide application significantly influenced chlorophyll contents and stomatal conductance. By limiting these major physiological components, it directly restricted P_n of plant.

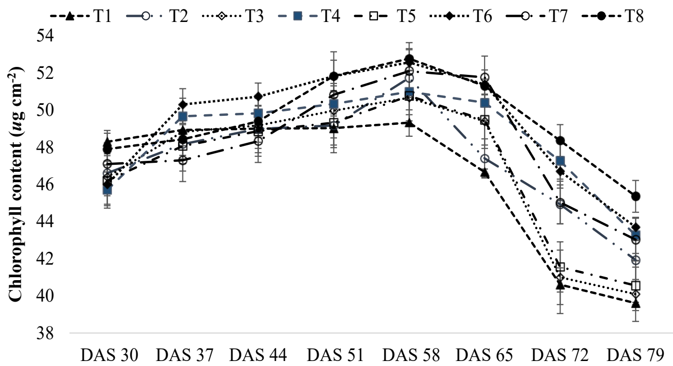

Figure 9: *Chlorophyll content (SPAD value) as affected by application of herbicide.*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.

Chlorophyll content (ug cm^{-2})

As the photosynthetic activity of the plant is directly influenced by the chlorophyll content of the leaves. Trends of chlorophyll content provide the valuable information about the plant health. Data related to the chlorophyll content is shown in Figure 9. Chlorophyll contents were showed increasing trend till 58 DAS, after that decrease in the chlorophyll content was noticed in all the treatments. During growing season highest chlorophyll contents (52.77 ug cm^{-2}) were recorded in the treatment stale seedbed + glyphosate + paraquat + atlantis during 58 DAS and lowest (49.33 ug cm^{-2}) chlorophyll contents were

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noted in treatment stale seedbed + no herbicide. At 58 DAS, highest chlorophyll contents revealed that during that period crop growth and development was maximum due to favorable conditions. Chlorophyll contents (52.77 $ugcm^{-2}$) of stale seedbed + glyphosate + paraquat + atlantis was at par with the plots treated with stale seedbed + glyphosate + atlantis and stale seedbed + paraquat + atlantis that showed chlorophyll content value (52.57 $ugcm^{-2}$) and (52.10 $ugcm^{-2}$) respectively. Whereas, the plot treated with stale seedbed + no herbicide resulted lowest (46.67 $ugcm^{-2}$) chlorophyll contents.

Chlorophyll contents at 65 DAS show a reduction in chlorophyll contents value, as the crop proceed in growth cycle due to which reduction in chlorophyll contents value was observed as a result. During the whole crop growth season, highest chlorophyll contents were recorded in treatment stale seedbed + glyphosate + paraquat + atlantis, as wheat crop showed luxurious growth and development due to less interference by weeds at any wheat crop growing stage. The data of the study revealed that, due to herbicidal use wheat crop showed under stress and resultantly at earlier stages less chlorophyll content was observed as compared to no herbicide treated plot (Hana *et al*., 2015; Bari *et al*., 2020). While, in treatment stale seedbed + no herbicide value of chlorophyll contents was lowest due to the unchecked weed growth. These outcomes are in line with the result of Chikoye *et al*. (2008) who stated that high weeds stress cause reduction in leaf area, chlorophyll content and crop yield.

Leaf area index (LAI)

The leaf area index (LAI) is defined as the ratio between total one-sided leaf area to per unit of ground area (Watson, 1947). Different herbicidal use depicted positive response to LAI of wheat. Overall herbicides use influenced the LAI which can be clearly seen in Figure 10. During the experimentation, highest (4.82) LAI was achieved in stale seedbed + paraquat at 60 DAS and minimum (2.85) LAI was recoded in plot having stale seedbed + no herbicide. In all treatment there was an increasing trend was recorded in leaf area index at 60 DAS but the data recorded 75 DAS revealed that there was decrease in LAI in each treatment. Which means that leaf area index began to decrease after 61 days, this may be attributed to crop growth stages, that started to change the growth stage from vegetative to its reproductive (maturity) except stale seedbed + no herbicide plot. This treatment showed maximum LAI 3.85 at 45 DAS which is started to decline after 46 DAS). This could be attributed to the weed infestation. Because under condition of limited resources and higher crop weeds competition crop plant tried to complete early crop growth cycle.

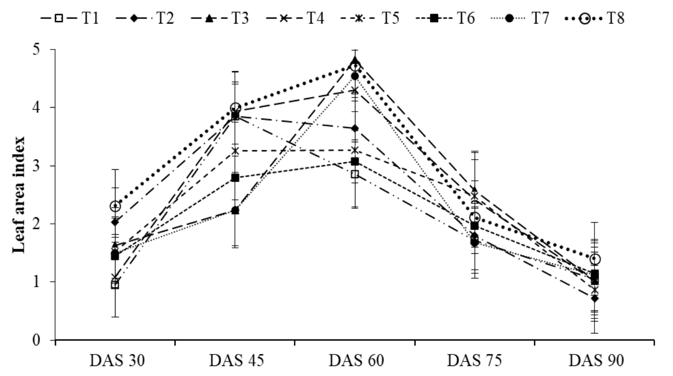

Figure 10: *Leaf area index of wheat as affected by application of herbicide.*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.

At 60 days, in reduce doses of herbicides application highest LAI (4.73) was reported in treatment stale seedbed + glyphosate + paraquat + atlantis which was that is followed by LAI of (4.54) in treatment stale seedbed + paraquat + atlatis. The plot with sole post-emergence herbicide depicted 4.30 LAI. Presented data clearly showed that treatments where pre-emergence, as well as post-emergence herbicides, were applied showed higher LAI as compared to treatments where only pre-emergence herbicides and not a single herbicide were applied to limit weeds density. Outcomes of this study were similar as (Khaliq *et al*., 2014; Misbahullah *et al*., 2019) who revealed that low levels of weeds density resulted in higher LAI in wheat crop.

Net assimilation rate (gm^{-2}day^{-1})

According to Beadle (1987), it is efficiency of a plant's photosynthetic process results in a rise in dry weight over time as the leaf area grows. Data related to NAR revealed that all treatments are varying significantly from each other (Figure 11). Overall, during whole growing season NAR was highest during early crop growth stage while decline in assimilation of synthates as moved towards reproductive and maturity stage. Highest (3.60 $gm^{-2}day^{-1}$) NAR was observed in stale seedbed + glyphosate + paraquat + atlantis at 45 DAS whereas, minimum NAR was (2.39 $gm^{-2}day^{-1}$) recorded in stale seedbed + glyphosate + paraquat at 45 DAS. During 45 DAS, next highest, NAR stale seedbed + atlantis treatment where 3.41 $gm^{-2}day^{-1}$ was observed. Treatments stale seedbed + paraquat and stale seedbed + glyphosate atlantis produced the NAR of (2.96 $gm^{-2}day^{-1}$) and (2.87 $gm^{-2}day^{-1}$), respectively. Collected data from the course of study depicted low NAR in treated plot of control and where no post-emergence herbicides were applied. This could be attributed to reduce dose of pre- and post-emergence herbicides that provide favorable environment throughout growing season due to less weed crop completion and produce more photosynthates during whole growing season. This finding is similar with the finding of Randhawa (2012) who revealed that low levels of weed densities showed in higher NAR $gm^{-2}day^{-1}$ of wheat.

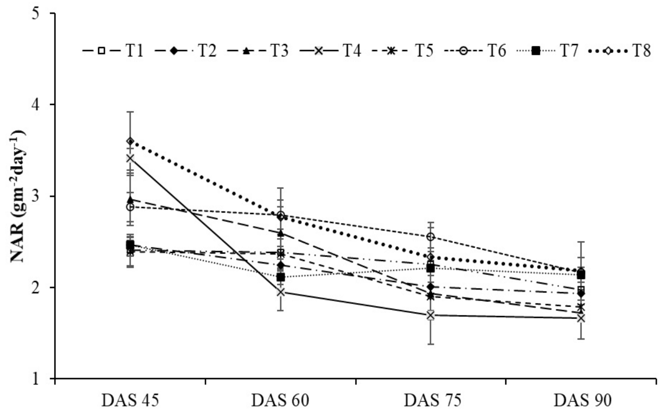

Figure 11: *Net assimilation rate ($gm^{-2}day^{-1}$) of wheat as affected by application of herbicide.*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}.

Leaf area duration (days)

It is the long-term correlation between data obtained from the leaf area index, which measures the amount of ground covered in relation to upper leaf surface area over time (Beadle, 1987). Data related to LAD showed that the temporal increase in days was significantly affected by herbicides use (Figure 12). The highest temporal increased (190.89 days) were depicted in plot treated with stale seedbed + glyphosate + paraquat + atlantis at 90 DAS was in treatment whereas, in stale seedbed + no herbicide showed lowest LAD (140.32 days). Next highest (175.59 days) LAD was observed in treatment stale seedbed + atlantis this can be attributed to the post-emergence herbicide that controlled the weeds after for longer period. Outcomes of this study showed that all treatment where sole pre-emergence herbicides or combined pre and post herbicides were applied showed significant higher LAD than control treatment. Particularly plot treated with reduced dose up to three quarter of recommended dose showed maximum LAD this can be due to the increase in the efficacy of herbicide to restrict weeds density and provide favorable environment to wheat for growth and development. These findings are similar to the study of Khaliq *et al*. (2014) who reported that plots with efficiently controlled weeds depicted maximum LAD.

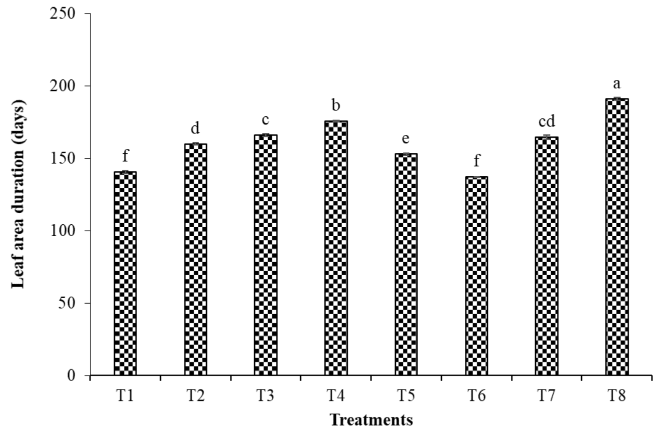

Figure 12: *Leaf area duration of wheat as affected by application of herbicide.*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}. Means with different letters are statistically significantly different by using at HSD α 0.05.

Crop growth rate ($gm^{-2}day^{-1}$)

The crop growth rate (CGR $gm^{-2}day^{-1}$) is the calculation increase in crop biomass per unit of time and ground area (Hunt, 1979). During this study, treatments showed a statistically significant influence on CGR ($gm^{-2}day^{-1}$). Data recorded showed significant difference among herbicide treated and

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untreated treatments on intervals bases Figure 13. Increase in the CGR was recorded in data that was recorded at 45-60 DAS. As the CGR was higher at 45 this period indicate that growth and development was also highest during this crop period. So, uptake of all available nutrients by crop was optimum and these resources were also used very efficiently in different growth processes during this period.

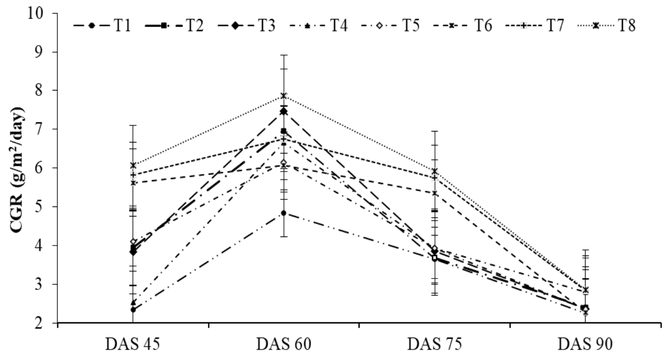

Figure 13: *CGR ($gm^{-2}day^{-1}$) of wheat as affected by application of herbicide.*

T_1: stale seedbed + no herbicide, T_2: stale seedbed +glyphosate @ 711 a.i $mLha^{-1}$, T_3: stale seedbed +paraquat-dichloride @ 494 a.i $mLha^{-1}$, T_4: stale seedbed +atlantis (mesosulfuron-methyl and iodosulfuron-methyl-sodium) @ 15 a.i gha^{-1}, T_5: stale seedbed +glyphosate @ 356 a.i $mLha^{-1}$+paraquat @ 247 a.i $mLha^{-1}$, T_6: stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: stale seedbed +paraquat @ 247 a.i $mLha^{-1}$+ atlantis @ 7.5 a.i gha^{-1}, T_8: stale seedbed +glyphosate @ 237 a.i $mLha^{-1}$+paraquat @ 165 a.i $mLha^{-1}$+ atlantis @ 5 a.i gha^{-1}.

During 60 days highest CGR (7.87 $gm^{-2}day^{-1}$) in plot stale seedbed + glyphosate + paraquat + atlantis whereas, statistically lowest (4.83 $gm^{-2}day^{-1}$) CGR was observed in control plot (No herbicide). Plot stale seedbed + glyphosate + paraquat + atlantis was followed closely by the treatment stale seedbed + paraquat in which recorded (7.46 $gm^{-2}day^{-1}$) CGR.

Decrease in CGR was observed during 75 DAS as at that time crop growth was almost completed and crop was turned into reproductive stage. Statistically maximum (5.91$gm^{-2}day^{-1}$) CGR was observed in stale seedbed + glyphosate + paraquat + Atlantis during this crop period, competition between crop and weeds was reduced by controlling the weed proliferation. As a result of these maximum nutrients and other available resources were utilized by crop only. There was no restriction in nutrient availability at critical period of crop growth and development. Crop growth rate was significantly lowest (3.64 $gm^{-2}day^{-1}$) in treatment stale seedbed + no herbicide, as weeds density was higher during entire crop season and weeds density were not managed and allowed to interfere with wheat crop growth and development stages. As weeds are efficient utilizer of resources, at initial wheat growth stages, weeds interfere with crop for limited available resources that significantly reduced the crop growth and development. This study is in line with the results of Rajcan and Tollenaar (1999) and Khaliq *et al*. (2014) they revealed that treatments with lo weeds density showed maximum CGR $gm^{-2}day^{-1}$.

Number of fertile tillers (m^{-2})

Fertile tillers (m^{-2}) as effected by stale seedbed and herbicide application showed (Table 2) statistically significant difference was depicted among treated and untreated herbicide plots. Treatment stale seedbed + glyphosate + paraquat + atlantis resulted higest (247) contrarily Stale seedbed + no herbicide treatment showed minimum (156) number of fertile tiller m^{-2}. Subtantial higher number of productive tiller were shown in treatment where combined pre-herbicide were applied for stale seedbed formation which was followed the application of atlantis as post-emergence herbicide to reduce weed crop competition at early critical stages of wheat crop. In results this treatment providing favorable conditions for growth and development due to less weeds density during whole growing season ultimately this favorable condition helps in producing more fertile tillers m^{-2}. Whereas, the less number of fertile tillers m^{-2} were recorded in stale seedbed + no herbicide which could be atttributed to higher weeds density of weeds. In this treatment crop were infested by weeds, this could be due to no herbicide application was undertaken prior and after the sown of crop. The plot treated with stale seedbed + atlantis showed low number of fertile tillers m^{-2} this could be due to higher weeds interference at early crop growth stages which compete with crop resources and resultantly wheat crop develop less number of tillers m^{-2}. Findings of this study are supported by results of Nanher and Raghuvir (2015) and Misbahullah *et al*. (2019) who stated that control of weeds by using herbicides resulted in substantial increase in number of productive tillers m^{-2}.

Grains spike^{-1}

A non-significant difference was observed for grains spike^{-1} among treatments (Table 2). The highest (53.67) grains were recorded in stale seedbed + glyphosate + paraquat + atlantis which was statistically at par with plot stale seedbed + paraquat

+ atlantis. While the lowest (50) grains were observed in the plot stale seedbed + no herbicide. The rest of the treated plots showed non-significant differences from each other. The highest number of grains spike^{-1} was observed where weeds were kept control at early growth stages by combined pre-emergence herbicide application afterward lateral flushes were checked by application of post-emergence herbicide. This weed control approach may increase the efficacy of herbicide to control weeds that help the wheat crop plant to improve growth and number grains spike^{-1}. The results of this study showed similarity with the findings of Mahmood *et al*. (2013) and Hameed *et al*. (2019) who stated that an increase in the number of grains spike^{-1} was observed where low weed density was recorded.

Table 2: *Effect of herbicides on yield and yield related parameters of wheat crop.*

Treatment	Number of fertile tiller (m^{-2})	Number of grain spike^{-1}	100 grain weight (g)	Grain yield (kg ha^{-1})
T1	156.33 e	50.00 b	2.13 b	1666.41 h
T2	213.00 d	52.00 ab	2.67 ab	2965.88 f
T3	217.00 d	51.33 ab	2.63 ab	2928.17 g
T4	221.66 cd	53.00 ab	2.62 ab	3091.06 e
T5	219.33 d	52.66 ab	2.71 ab	3121.33 d
T6	239.66 ab	52.66 ab	2.83 ab	3576.4 b
T7	232.33 bc	53.33 a	2.58 ab	3209.69 c
T8	246.33 a	53.66 a	3.18 a	4215.02 a
HSD Tukey's	12.97	3.24	0.85	14.15

T_1: Stale seedbed +no herbicide, T_2: Stale seedbed +glyphosate @ 711 a.i mLha^{-1}, T_3: Stale seedbed +paraquat-dichloride @ 494 a.i mLha^{-1}, T_4: Stale seedbed +atlantis @ 15 a.i gha^{-1}, T_5: Stale seedbed +glyphosate @ 356 a.i mLha^{-1}+paraquat @ 247 a.i mLha^{-1}, T_6: Stale seedbed +glyphosate @ 356 a.i mLha-1 + atlantis @ 7.5 a.i gha^{-1}, T_7: Stale seedbed +paraquat @ 247 a.i mLha^{-1}+ atlantis @ 7.5 a.i gha^{-1}, T_8: Stale seedbed +glyphosate @ 237 a.i mLha^{-1}+paraquat @ 165 a.i mLha^{-1}+ atlantis @ 5 a.i gha^{-1}. Means with different letters are statistically significantly different by using at HSD α 0.05.

100-grains weight (g)

100-grain weight data depicted a positive response to herbicide-treated plots Table 2. The highest 100-grain weight (3.18 g) was recorded in stale seedbed + glyphosate + paraquat + atlantis. Contrarily, the lowest (2.13 g) 100-grain weight was recorded in a stale seedbed + no herbicide. The rest of the treated plots were statistically at par with each other. The high 100-grain weight could be attributed to stale seedbed formation which was followed by post-emergence herbicide that resultantly crop get prolonged favorable environment to utilize resources efficiently and improve growth process to accumulate more synthates to increase productivity. study results supported by findings of Ali *et al*. (2016) who stated that pre emergence and post emergence herbicides control the weeds efficiently which resulted in improve 100-grains weight ultimately wheat crop productivity also improve. Statistically lowest 100-grains weight was observed where only stale seedbed was formed by using pre-emergence herbicides. This significant low 100 grain weight could be accredited to prologed interfernce period of weeds which limit crop plant resources during critical stages of crop. So, this preciouse resources of crop plants were exposed to weeds. Major portion was used by these undesired plant. Which resulted in the reduction of in wheat growth owing to the less availability of plant resources. In this competitive environment wheat crop plants are unable to accummulate synthates efficiently.

Grains yield (kg ha^{-1})

Presented yield data showed the significant difference among all treatments (Table 2). Statistically highest 4215 kg ha^{-1} grain yield was observed in the treatment stale seedbed + glyphosate + paraquat + atlantis and while statistically lowest 1666.41 kg ha^{-1} of grain yield was observed in plot stale seedbed + no herbicide. Next best treatment was stale seedbed + glyphosate + atlantis that showed grain yield of 3576.4 kg ha^{-1} and it was statistically similar with the treatment stale seedbed + paraquat + atlantis in which yield of grain was 3209.69 kg ha^{-1}. Highest grain yield was achieved in treatment where stale seedbed was formed by using pre-emergence herbicides (glyphosate, paraquat) which was followed post-emergence herbicide. Increase in grain yield could be due to better WCE in this treatment which resulted in wheat crop growth improvement. Crop plants utilized available resources efficiently that put a positive influence on crop growth processes. Statistically lowest yield of grain was observed in stale seedbed + no herbicide. This could be attributed to the higher interspecific weeds and crop competition. Weeds are most efficient user of plant resources as compared to wheat crop plants because majority of weeds plants use C_4 while wheat crop plant use C_3 metabolic pathway to fix carbon. So, in that way weeds plant utilizes the major portion of plant resources that resulted in the reduction of crop growth and development. Treatments where stale seedbed was formed by convention method and not a single pre-emergence herbicide was used faced severe weed interference at early crop critical stages. The plots with stale seedbed formed by sole or integrated reduced doses of pre-emergence herbicides. In these treatments wheat crop that was exposed to competition to weeds at lateral crop stages. So, wheat crop growth and development were damaged at lateral crop stages which severely limit crop yield. These results are at par with the results of Naseer ud Din *et al*. (2011), Nanher and Raghuvir (2015) and Hameed *et al*. (2019) who stated that pre and post emergence herbicide use efficiently control the weeds which resulted increase in grain yield of wheat crop.

Conclusions and Recommendations

In light of the obtained data, it is concluded that farmers should adapt stale seedbed technology by using reduced dose of pre and post emergence herbicides to avoid early grassy weeds and broad-leaved weeds. Here in this study, we also concluded that stale seedbed technology in combination with reduce dose up to three quarter also showed a check on weeds growth at early stages to reduce weeds interference and maximize the economical wheat yield 40% than no herbicide treated plot.

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Novelty Statement

In this field study, we used stale seedbed preparation with the integration of pre-emergence and post-emergence herbicides in different combination. This approach will help in reducing weeds at early stages and improve yield attributes of crop productivity.

Author's Contribution

Muhammad Waqas Yonas: Conducted field trial, data analysis and preparing first draft.
Khuram Mubeen: Planned the study.
Muhammad Irfan and Mudassir Aziz: Proof reading.
Muhammad Irfan and Saad ur Rehman: Helped in data compilation and analysis.
Muhammad Ayaz Shahzad: Helped in technical issues related to irrigation.
Shoaib Zawar: Helped in field related arrangements i.e., data collection.

Conflict of interest
The authors have declared no conflict of interest.

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