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Research Article

Integrative effect of NPK fertilization and weed management practices on growth indices and yield of wheat under agro-climatic condition of Quetta-Pakistan

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Abstract

The inhibitory effect of weeds on crop can be minimized by changing nutrient supply and weed management practices. For this purpose, a field experiments was carried out during 2014-15 at the experimental field of ARI, Quetta based on complete randomized block design in factorial arrangement and were replicated thrice. In the experiment, five fertilizer rates (0-0-0, 100-80-50, 135-90-50, 170-100-50, 205-110-50 NPK kg ha^{-1}) were tested across different weed management practices (no weeding, herbicide application, hand hoeing and allelopathic weed control) in an integrated manner. The results showed that the medium fertilizer rate (135-90-50 kg NPK ha^{-1}) produced maximum tillers m^{-2} (437.50), spike length (12.12 cm), spikelets spike^{-1}(29.08), grain spike^{-1} (78.33), seed index (42.05 g), harvest index (37.7%), grain yield (4.51 t ha^{-1}), leaf N (3.91%), P (0.94%) and K (4.05) concentration and uptake. The increasing fertilizer rates particularly N increased vegetative growth over reproductive growth as evidenced from higher LA (316.92 cm^{-2} plant^{-1}) and LAI (1.96). In case of weeds management, the herbicide application or hand hoeing effectively controlled weeds by 85.47 and 78.73% that resulted in increased all wheat traits. According to linear regression analysis, grain yield was positively and significantly associated with LAI (r = 0.93), tillers m^{-2} (r = 0.94), harvest index (r = 0.96), LAD (r = 0.97) and NAR (r = 0.88) respectively. Consequently, weed crop competition was minimized and wheat yield was enhanced when fertilizer rate of 135-90-50 NPK kg ha^{-1} was used and weeds were controlled either by herbicide application/hand hoeing.

Keywords: Allelopathic weed control; Growth indices; Herbicide; Interculture; NPK fertilizer; Weeds; Wheat

Introduction

Nutrients play an important role in the growth, development, production and quality of cereal crops including wheat. Among all essential nutrients, the major nutrients required by wheat crop are nitrogen (N), phosphorus (P) and potassium (K). Among the macronutrients, N is required in large amount which is the major nutrient needed for increasing growth and yield of crops and its supply in balanced form is reflected in bumper crop. According to Brady and Weil **[1]** that the higher N rates substantially transform carbohydrates into proteins leading to formation of more protoplasm and play key role in overall growth processes. However, the requirement of P is lower than N and K but its role is quite critical in pant growth particularly in early growth stages and is responsible for the transfer of energy during entire growth period. On dry weight basis, the quantity of P needed is 10 times lower than N and K. They further stated that P is essential in many biochemical reactions including photosynthesis, cell division, respiration and others growth processes. In these growth processes, the energy involved is ATP which requires the continuous supply of external P from soil. And above all, it is beneficial for setting of flowering, seed formation, crop maturity and proliferation of rooting. So, its optimum application improve yield and yield components of wheat.

The grain yield of wheat is tremendously affected by N application because low applicatioin rate reduce the overall wheat growth and yield and higher application rates enhanced vegetative growth at the cost of reproductive growth that led to low grain yield of wheat **[2]**. According to Liang *et al.* **[3]** that the optimum N application of 80-120 kg ha^{-1} produced improved growth and yield of wheat. Some researchers like Sobh *et al.* **[4]**, Alam *et al.* **[5]** and Kumar *et al.* **[6]** reported that N application rate of 200 kg ha^{-1} resulted in enhancement of agronomic and physiological characteristics of wheat. Chauhan **[7]** revealed that fertilizer rate of 120-60-40 NPK kg ha^{-1} increased the growth characteristics of wheat as compared to control where no fertilizer was applied. Agronomic traits of wheat were increased when 120 and 150 kg N ha^{-1} was applied while the lower and higher rates resulted in reduction of all agronomic traits **[8]**.

The application of phosphorus and potassium to wheat crop is essential. Both P and K increases seed maturity and seed development and critical for proliferation of root. Wheat plants with extensive rooting can explore more volume of soil for nutrients absorption **[7]**. In soil system of Pakistan most of the nutrients are not easily available to crop due to calcareous and alkaline nature of soil and under this situation crop hardly recover only 11-19% of nutrients applied as fertilizer **[9]**. It has been observed that the increasing rate of fertilizer exerted beneficial effects on crops particularly wheat and the overall agronomic characteristics of wheat such as plant height, spike length, spikelets $spike^{-1}$, grains $spike^{-1}$, seed index, biological yield, grain yield and harvest index were improved **[10]**. The application of 108 P kg ha^{-1} in wheat crop resulted in increased P uptake, leaf P concentration, more tillers m^{-2} and higher biological and grian yield **[11]** while in Pakistan the researcher like Khalid *et al.* **[12]** observed that the application of 45 kg P ha^{-1} produced higher wheat grain yield and improved the growth of wheat by increasing the yield components and growth indices.

The role of potassium as a quality enhancer in all vegetables, cereals and fruits is evident that its application helps in improving the plant nutrition, create resistance in plants under stress conditions caused by drought, disease and salinity and above all its application improves the storage life of most crops especially cereals and fruits **[13]**. Bahmanyar and Ranjbar **[14]** reported that K application to wheat crop resulted in inceased agronomic traits like plant height, seed index, tillers m^{-2}, leaf K concentration and uptake and ultimately enhanced grian yield. The application of K improved photosynthetic activities that resulted in yield enhancement **[15-17]**.

However, one of the factors for low nutrient use efficiency of wheat crop is weed infestation because they not only compete with wheat crop for nutrient but also for moisture, space and light that ultimately resulting in low wheat production. Weed infestation is one of the major biotic constraints in agriculture production system **[18]**. It has high competitive potential as compare to crops because they are easily adopted even in the harsh environment with limited resources **[19,20]**. Generally, the competitive interaction between weed and crop is intricate because both are competing for the same resources such as space, moisture, light and nutrients **[21,22]**. The availability of space is necessary for growth of plants either weed or crop and due to high competitive potential weed can occupy more space in early growth stage and suppress the crops growth **[23]**. The second most competitive target for both weed and crop is the available moisture which is vital for their growth and as weeds get succeeded in early establishment, can compete more over crop for moisture and thus reduce crop growth **[24]**. Its incursion considerably affects incomes and product value and sometimes the entire crop failure might be resulted if weed are not controlled properly **[25, 26]**. In Pakistan, the annual losses due to weed infestation in wheat crop are estimated higher than Rs. 28 billion **[27]**.

Weed control strategies comprised of Mechanical (physical) and chemical methods such as summer ploughing, hand weeding, hoeing, tillage, mulching and use of herbicides. As compared to physical weed control, chemical weed control is more effective, low cost involved and time saving. Wheat is largely infested by narrow leaves weed which remain dominant over broad leaves weed **[28, 29]**. The time of herbicides application is very critical as reported by Balyan *et al.* **[30]** and Naseer-ud-Din *et al.* **[31]** that the application of isoproturon 35 DAS controlled weed effectively but further delay resulted in poor control. In addition, allelopathic approach can be used for weed control because it is ecologically safe, economical and play a vital role in the development of sustainable agriculture **[32, 33]**. The application of allelopathic compounds in the form of plant water extract offers an encouraging substitute of chemical herbicides for sustainable and environmentally friendly weed management **[34]**. Keeping in view the significance of fertilizer rates and weed control in crop production, the present study was aimed to minimize weed crop competition by using NPK fertilizer integrated with weed management practices for enhancement of wheat yield.

Materials and methods

The experiment was conducted during the year 2014 and 2015 to investigate the influence of different nitrogen (N), phosphorus (P) and potassium (K) fertilizer rates integrated with different weed management practices for enhancement of wheat yield. The experiment was designed in RCBD (randomized complete block design) in factorial arrangement. Four different fertilizer rates (factor-A) were tested across four weed management practices (factor-B) which were replicated thrice while keeping plot size of 48 m^2. The details of treatment combinations are given in (Table 1) and that of factor-A and B are as under:

Factor (A) = Fertilizer treatments = 05

F1 = 0-0-0 NPK kg ha^{-1}
F2 = 100-80-50 NPK kg ha^{-1}
F3 = 135-90-50 NPK kg ha^{-1}
F4 = 170-100-50 NPK kg ha^{-1}
F5 = 205-110-50 NPK kg ha^{-1}

Factor (B) = Weed management techniques = 04

W1= No weeding
W2= Herbicides application:
i) Bromoxynil+MCPA @750 ml ha^{-1} for broadleaf weeds
ii) Clodinafop-propargyl @ 300 g ha^{-1} for narrowleaf weeds
W3= Hand hoeing (after first and second irrigation)

W4=Allelopathic weed control (Sunflower extract @ 6 L ha^{-1} at 30 + 40 DAS)

Table 1. Treatment combinations

T1 = W_1F_1	T6 = W_2F_1	T11 = W_3F_1	T16 = W_4F_1
T2 = W_1F_2	T7 = W_2F_2	T12 = W_3F_2	T17 = W_4F_2
T3 = W_1F_3	T8 = W_2F_3	T13 = W_3F_3	T18 = W_4F_3
T4 = W_1F_4	T9 = W_2F_4	T14 = W_3F_4	T19 = W_4F_4
T5 = W_1F_5	T10 = W_2F_5	T15 = W_3F_5	T20 = W_4F_5

Cultural practices

The field was divided into sub-plots according to the experimental description. Buffer zone was built up between the plots where herbicides were used to control the drifting of herbicides into the no weedy plots. Sowing was carried out on 15th November by single coulter hand drill using seed rate of 125 kg ha^{-1}. The fertilizers were applied as per treatments under factor A. All the phosphorus as single super phosphate, potassium as murate of potash and ¼ nitrogen was applied during sowing time. However, remaining nitrogen was applied into split doses during 2nd and 3rd irrigations.

Weed management techniques

Weed management techniques were adopted as per treatments under factor B. Herbicides were applied for broadleaf weeds on 26 days after sowing and for narrow leaf weeds on 40 days after sowing. Sunflower extract as allelopathic weed control **[35]** was applied 40 days after sowing.

Soil and plant analysis

A composite soil samples with depth of 15 cm were collected from the experimental field and analysed for sol texture, pH, electrical conductivity (EC), organic matter and ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) extractable phosphorus (P) and potassium (K). Hydrometer method was used for soil textural analysis [36], pH and EC were determined in 1:5 soil and water suspension at 25 °C according to the method described by McKeague **[37]** and McLean **[38]** and organic matter by oxidizing method **[39,40]**. While, AB-DTPA extraction solution was used for extracting P and K **[41]**. In the clear filtrate of AB-DTPA soil extract, phosphorus was determined on Spectrophotometer at 880 nm wavelength and potassium on Flame Photometer.

Flag leaf was collected from 10-30 pants in each plot at milking stage. The samples were then put in the paper envelopes, labeled them with permanent marker and delivered to the Laboratory of Soil and Water Testing Laboratory ARI Sariab Quetta the same day and stored them over there at 20 °C for next coming working day. The samples were decontaminated and washed following the method of Sonneveld & Dijk **[42]**, oven dried at 80 °C, ground to 20 mesh and stored in plastic bags at 4 °C in the Lab. for target analysis. Weighed 0.5 g of the prepared plant sample and wet digested using hot sulfuric acid with repeated additions of 30% hydrogen peroxide (H_2O_2) until the digestion was completed, then this digest was used for the determination of total nitrogen, phosphorus and potassium **[43]**. For phosphorus, Pipetted 10 ml of the digest into a 100 ml volumetric flask, added 10 ml ammonium-vanadomolybdate and diluted the solution with Deionized water upto the mark **[44]**. Then, read the absorbance of the blank, standards, and samples after 30 minutes at 410-nm wavelength on Spectrophotometer. The potassium in the digest was determined directly by Flame Photometer **[45]**. Total nitrogen was determined by Kjeldhal method **[46]**.

Statistical analysis

The collected data statistically analysed using analysis of variance and Least Significance Difference (LSD) test at probability (P) level 0.05 was conducted for comparison of mean. Correlation was established among the studied parameters as influenced by various treatments. All the statistical analysis was computed on Statistix 8.1 software (Math Soft Inc., Cambridge, MA, USA).

Results

The pre soil analysis of experimental site revealed that the soil was silty clay loam in texture, non-saline, alkaline in nature, low in organic matter contents (0.64%), total nitrogen (0.032%) and AB-DTPA extractable phosphorus (2.75 ppm) but high in AB-DTPA extractable potassium (134 mg kg^{-1}). The effect of different fertilizer rates and weed management practices on wheat crop were studied in an integrated manner. Both agronomic and physiological traits of wheat were observed along with nutrient accumulation and uptake across both factors of fertilizer rates and weed management practices. The studied agronomic traits of wheat were included plant height (cm), tillers (m^{-2}), spike length (cm), spikelets $spike^{-1}$, grains $spike^{-1}$, seed index (g), biological yield (t ha^{-1}), grain yield (t ha^{-1}) and harvest index (%) respectively. Whereas, the physiological traits of wheat were included leaf area (cm^2 $plant^{-1}$), leaf area index (LAI), leaf area duration (LAD) (days), net assimilation rate (NAR) (g m^{-2} day^{-1}) and crop growth rate (CGR) (g m^{-2} day^{-1}). Together with that, wheat leaf nutrient concentration (%) was recorded for nitrogen (N), phosphorus (P) and potassium as well as their uptake (kg ha^{-1}). In control plot where weeds were not controlled but NPK fertilizer was applied, the observations were noted for weed biomass (kg ha^{-1}), weed density (m^{-2}) and weed frequency (%).

Agronomic traits of wheat

The statistical analysis for all agronomic traits of wheat showed highly significant differences across different fertilizer rates and weed management practices and their interaction. The results indicated that maximum plant height (86.88 cm), biological yield (12.72 t ha^{-1}), leaf area (316.92 cm^2 $plant^{-1}$), leaf area index (1.96), weed biomass (6172.9 kg ha^{-1}), weed density (166 m^{-2}) and weed frequency (6.29%) were recorded in plot when higher fertilizer rate of 205-110-50 kg NPK ha^{-1} was applied and their respective lower values were found in control plot where no fertilizer was applied. However, lower fertilizer rate (100-80-50 kg NPK ha^{-1}) also improve these traits over control but in comparison to higher fertilizer rates these traits were reduced. In case of other important yield components, the fertilizer rate of 135-90-50 kg NPK ha^{-1} produced higher number of tillers m^{-2} (437.5), spike length (12.12 cm), spikelets $spike^{-1}$ (29.08), grains $spike^{-1}$ (78.33), seed index (42.05 g), harvest index (37.78) and grain yield (4.51 t ha^{-1}) which were found in decreasing trend on higher fertilizer rates while control plot expressed lowers values for these traits (Table 2).

Agronomic traits of wheat crop were significantly ($p<0.05$) affected by weed management practices as shown in (Table 3). Both chemical weeds control and hand hoeing produced statistically higher but at par results for spike length, spikelets $spike^{-1}$, seed index and harvest index. While biological yield was found at par for chemical weed control and allelopathic weed control. Among them, the maximum plant height (86.17 cm), seed index (40.90 g), biological yield (12.01 t ha^{-1}), harvest index (33.73) and grain yield (4.11 t ha^{-1}) were recorded in plot when weeds were controlled by herbicide application. Whereas, weed control by hand hoeing produced greater number of tillers m^{-2} (425.93), spike length (12.18 cm), spikelets $spike^{-1}$ (27.80) and grains $spike^{-1}$ (74.67) respectively. However, the weedy check (no weed control) exhibited lower values for all the agronomic traits of wheat. It demonstrates that without weeding the optimum yield of wheat cannot be achieved because in presence weed infestation all yield contributing factors are affected that ultimately affect grain yield of wheat.

The interactive effect of fertilizer rates and weed management practices on agronomic traits of wheat showed significant ($p<0.05$) differences as shown in (Table 4). The interaction of 205-110-50 kg NPK ha^{-1} x herbicide application expressed higher plant height (91.25 cm) while maximum number of tillers m^{-2} (545.00), spike length (13.13 cm), spikelets spike^{-1} (33.67) and grains spike (89.67) and seed index (44.43 g) and grain yield (5.12 t ha^{-1}) were recorded at the interactive effect of 135-90-50 kg NPK ha^{-1} x hand hoeing. Statistically the grains spike^{-1}, seed index and grain yield manifested at par differences at the interaction of 135-90-50 kg NPK ha^{-1} x hand hoeing and 135-90-50 kg NPK ha^{-1} x herbicide application. However, greater biological yield was noted at higher fertilizer rates of 170-100-50 and 205-110-50 kg NPK ha^{-1} with herbicide application, hand hoeing and allelopathic weed management which were statistically at par from each other.

Physiological traits of wheat

Growth indices of a crop are the best indicators for assessing the effect of fertilizer and weed control strategies. So, in this study different growth indices like leaf area, leaf area index, leaf area duration (LAD), net assimilation rate (NAR) and crop growth rate (CGR) were recorded across the interactive effect of fertilizer rates and weed management practices. The analysis of variance regarding these traits showed significant ($p<0.05$) differences for NPK rates and weed control measures and their interaction. The LSD test for mean comparison showed maximum leaf area (316.92 cm^2 plant^{-1}) and leaf area index (1.96) on higher fertilizer rate of 205-110-50 kg NPK ha^{-1} while `higher leaf area duration (100.43 days), NAR (5.06 g m^{-2} day^{-1}) and CGR (22.90 g m^{-2} day^{-1}) were found at fertilizer rate of 135-100-50 kg NPK ha^{-1}. Statistically, NAR was at par at both fertilizer rates of 135-100-50 kg NPK ha^{-1} and 170-110-50 kg NPK ha^{-1}. Among these traits, LAD, NAR and CGR of wheat started decline on higher fertilizer rates. Furthermore, in control plot all physiological traits were decreased statistically (Table 2).

Like agronomic traits, the studied physiological traits of wheat were also varied significantly ($p<0.05$) across different weed management practices. The LSD test for mean comparison revealed maximum leaf area (309.13 cm^2 plant^{-1}), leaf area index (1.82) and CGR (22.24 g m^{-2} day^{-1}) of wheat when weeds were controlled by hand pulling/hoeing which were statistically at par with herbicide weed control. While higher NAR was recorded in plot when weeds were controlled by herbicide application only. In case of control plot where weed infestation was allowed, these traits were suppressed substantially. Allelopathic weed management also helped in improvement of these traits over control but was less effective as compared to herbicide application and hand pulling of weeds (Table 3).

The interactive effect of fertilizer rates and weed management practices showed significant ($p<0.05$) differences for leaf area, leaf area index, LAD, NAR and CGR as given in (Table 4). The maximum leaf area (352.30 cm^2 plant^{-1}) and leaf area index (2.63) were found at the interaction of 205-110-50 kg NPK ha^{-1} x hand pulling weed control which were statistically at par with same fertilizer rate x herbicide application. In case of LAD and NAR, the interactive effect of 135-90-50 kg NPK ha^{-1} x herbicide application revealed higher LAD (118.22 days) and NAR (6.20 g m^{-2} day^{-1}) while greater CGR (25.38 g m^{-2} day^{-1}) was note at the same fertilizer rate but with hand pulling weeds control.

Leaf NPK concentration (%) of wheat

Wheat leaf NPK concentration were fluctuated significantly ($p<0.05$) across different fertilizer regimes (Table 2). The LSD test for comparison of mean ($p<0.05$) showed higher N (3.91%), P (0.94%) and K concentration (4.05%) at fertilizer rate of 135-90-50 kg NPK ha^{-1}. While, minimum leaf N (2.48%), P (0.24%) and K concentration (2.93%) were observed at zero fertilizer rate. Statistically, N and K concentration at two fertilizer rate of 135-90-50 and 170-100-50 kg NPK ha^{-1} were at par while P concentration at 170-100-50 and

205-110-50 kg NPK ha^{-1} was found non- significant.

Table 2. Effect of different fertilizer rates on wheat traits and leaf NPK concentration and uptake

Plant traits	Fertilizer rates (N-P-K kg ha^{-1})					S.E.	LSD (5%)
	0-0-0	100-80-50	135-90-50	170-100-50	205-110-50		
Plant height (cm)	74.45d	81.73c	84.54b	85.96ab	86.88a	0.74	1.51
Tillers (m^{-2})	220.92e	332.00d	437.50a	398.08b	365.42c	5.71	11.55
Spike length (cm)	9.83d	11.21c	12.12a	11.58b	11.36c	0.10	0.20
Spikelets spike^{-1}	20.83c	25.33b	29.08a	26.91ab	24.83b	1.13	2.29
Grains spike^{-1}	57.08b	66.08c	78.33a	70.58 b	64.92c	0.99	2.01
Seed index (g)	34.62e	38.94c	42.05a	41.03b	37.08d	0.37	0.76
Biological yield (t ha^{-1})	9.83e	10.91d	11.83c	12.38b	12.72a	0.14	0.28
Grain yield (t ha^{-1})	1.99e	3.51d	4.51a	4.10b	3.69c	0.06	0.13
Harvest index (%)	20.24d	32.08b	37.78a	32.53b	28.70c	0.43	0.86
Leaf area (cm^2 plant^{-1})	248.13	277.33c	284.41bc	295.11b	316.92a	5.57	11.27
Leaf area index	0.72e	1.24d	1.47c	1.64b	1.96a	0.07	0.14
Leaf area duration (days)	48.93d	80.97c	100.43a	87.68b	82.31c	2.65	5.36
Net assimilation rate (g m^{-2} day^{-1})	3.18d	4.34b	5.06a	4.86a	3.66c	0.15	0.30
Crop growth rate (g m^{-2} day^{-1})	17.64e	20.63c	22.90a	21.81b	19.31d	0.49	0.98
Weed biomass (kg ha^{-1})	4538.1d	4633.5d	5377.9c	5844.1b	6172.9a	107.5	217.8
Weed density (m^{-2})	96.92e	108.58d	144.67c	158.92b	166.00a	2.89	5.85
Weed frequency (%)	5.13c	5.85b	6.06ab	6.26a	6.29a	0.13	0.26
N (%)	2.48c	2.94b	3.91a	3.77a	3.02b	0.17	0.34
P (%)	0.24d	0.39c	0.94a	0.56b	0.52b	0.03	0.06
K (%)	2.93c	3.38b	4.05a	3.92a	3.44b	0.17	0.34
N-uptake (kg ha^{-1})	83.15d	98.62c	123.23a	113.69b	107.0bc	4.14	8.38
P-uptake (kg ha^{-1})	6.83c	16.14b	20.51a	20.44a	20.38a	0.89	1.80
K-uptake (kg ha^{-1})	48.18d	75.08c	109.81a	105.20ab	100.36b	3.78	7.66

In each row, means followed by common letter are not significantly different at 5% probability level

Table 3. Effect of different weed management practices on wheat traits and leaf NPK concentration and uptake

Plant traits	Weed management practices				S.E.	LSD (5%)
	W_1	W_2	W_3	W_4		
Plant height (cm)	78.04d	86.17a	84.42b	82.22c	0.67	1.34
Tillers (m^{-2})	179.93d	406.13b	425.93a	391.13c	5.10	10.33
Spike length (cm)	8.99c	12.00a	12.18a	11.71b	0.09	0.18
Spikelets spike^{-1}	19.73b	27.40a	27.80a	26.67a	1.01	2.05
Grains spike^{-1}	52.93d	72.47b	74.67a	69.53c	0.89	1.80
Seed index (g)	34.91c	40.90a	40.78a	38.39b	0.33	0.68
Biological yield (t ha^{-1})	10.55c	12.01a	11.61b	11.96a	0.12	0.25
Grain yield (t ha^{-1})	2.47d	4.11a	3.95b	3.68c	0.06	0.11
Harvest index (%)	23.34c	33.73a	33.48a	30.51b	0.38	0.77
Leaf area (cm^2 plant^{-1})	233.89c	302.84a	309.13a	291.67b	5.06	10.25
Leaf area index	0.52c	1.76a	1.82a	1.52b	0.06	0.12
Leaf area duration (days)	58.50c	91.60a	87.97a	82.18b	2.37	4.79
Net assimilation rate (g m^{-2} day^{-1})	3.16d	5.10a	4.76b	3.87c	0.13	0.27
Crop growth rate (g m^{-2} day^{-1})	17.03c	21.61ab	22.24a	20.95b	0.43	0.88
Weed control (%)	0.0d	85.47a	78.73b	69.33c	2.36	4.77
N (%)	2.22c	3.71a	3.56ab	3.41b	0.15	0.20
P (%)	0.17c	0.60a	0.58ab	0.54b	0.03	0.05
K (%)	1.32b	4.40a	4.25a	4.20a	0.15	0.31
N-uptake (kg ha^{-1})	73.25c	121.12a	115.77ab	110.42b	3.70	7.50
P-uptake (kg ha^{-1})	8.24c	21.48a	19.48b	18.24b	0.79	1.61
K-uptake (kg ha^{-1})	62.34c	99.20a	97.10ab	92.28b	3.38	6.86

Mean followed by common letters are not significantly

The higher weed infestation enhanced weed crop competition for all limited resources including nutrients as evidenced by no weeding plot (W1) where wheat leaf N, P and K concentration was reduced by 40.16, 72.0 and 70.0% over herbicide application (W2); 37.64, 70.9 and 68.94% over hand hoeing (W3) and 35.0, 68.52 and 68.60%o over allelopathic weed control (W4) respectively. Among the four weed management practices, weed control through herbicide application exhibited higher wheat leaf N (3.71%), P (0.60%) and K concentration (4.40%) followed by hand hoeing. Statistically, wheat leaf N and P concentration were at par when weeds were controlled by herbicide(W2) and by interculuring (W3) while K concentration was found non-significant at all weed management practices (i.e. W2, W3 and W4) (Table 3).

The interactive effect of fertilizer rates x weed management on wheat leaf N, P and K concentration was differed significantly (Table 4). The non-significantly higher concentration of N, P and K were exhibited by the interaction of fertilizer rates of 135-90-50 and 170-100-50 kg NPK ha^{-1} with weed management of W2, W3 and W4. While, the lower leaf N (1.75%), P (0.12%) and K concentration (1.22%) were found at the interaction of zero fertilizer rate with W1 (no weeding). But, their minimum concentration of 1.58, 0.18 and 1.28% was recorded at the interaction of 100-80-50 NPK kg ha^{-1} x W1 (no weeding).

NPK uptake (kg ha^{-1}) of wheat

Wheat nutrients uptake varied significantly as affected by different fertilizer rates (Table 4). The LSD test for comparison of mean ($p<0.05$) displayed higher uptake of N (123.23 kg ha^{-1}), P (20.51 kg ha^{-1}) and K (109.81 kg ha^{-1}) at fertilizer rate of 135-90-50 kg ha^{-1} followed by 113.69, 20.44 and 105.20 kg NPK ha^{-1} at the fertilizer rate of 170-100-50 kg ha^{-1}. While, minimum N, P and K uptake (83.15, 6.83 and 48.18 kg NPK ha^{-1}) were observed at zero fertilizer rate. Statistically the uptake of P was at par at fertilizer rates of 135-90-50, 170-100-50 and 205-110-50 kg NPK ha^{-1}.

The presence of weeds in wheat crop increased weed crop competition that resulted in reduction of wheat nutrient uptake as evidenced by no weeding plot (W1) that resulted in reducing N, P and K uptake of wheat by 39.52, 61.64 and 37.15% over chemical weed control (W2). Among them, chemical weed control exhibited higher N, P and K uptake (121.12, 21.48 and 99.20 kg ha^{-1}) followed by 115.77, 19.48 and 97.10 kg NPK ha^{-1} at W3 (interculturing). The weed infestation as in no weedy plot (W1) indicated lower nutrients uptake of wheat crop (73.25, 8.24 and 62.34 kg NPK ha^{-1}).

The interactive effect of fertilizer rates x weed management on N, P and K uptake of wheat crop was significant as presented in (Table 4). The result showed higher uptake of N, P and K (143.46, 26.42 and 126.34 kg ha^{-1}) at the interactive effect of fertilizer rate (135-90-50 kg NPK ha^{-1}) x W2 (herbicide application. While, the interaction between zero fertilizer rate and no weeding (W1) showed lower nutrient uptake of 59.85, 5.33 and 41.09 kg NPK ha^{-1}. Non-significantly higher P uptake was observed at the interaction of higher fertilizer rates (135-90-50, 170-100-50 and 205-110-50 kg NPK ha^{-1}) x W2. In case of K uptake, the interactive effect of higher fertilizer rates with W2, W3 and W4 exhibited statistically at par differences but comparatively higher uptake while the interaction of zero fertilizer rate with weed management of W2, W3 and W4 indicated at par lower K uptake as compared to other interactions (Table 4).

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Table 4. Plant traits as affected by the interactive effect of fertilizer rates x weed management practices

Fertilizer rates (N-P-K) x weed management practices		Plant traits							
		Plant height (cm)	Tillers (m-^{2})	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}	Seed index (g)	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})
0-0-0 kg ha^{-1}	No weeding	74.32lm	149.33n	7.63j	14.67k	45.33h	32.39i	9.40g	1.85j
	Herbicideappl.	75.77klm	250.33i	10.63g	24.00f-i	60.33ef	35.14fgh	9.83g	2.07ij
	Hand pulling	74.31lm	237.0ij	11.32f	22.00g-j	64.00de	36.11fg	9.6g	2.01j
	Allelopathic weed management	73.39m	247.0i	9.83h	22.67f-j	58.67f	34.85gh	10.47f	2.03j
100-80-50 kg ha^{-1}	No weeding	77.13jkl	174.67lm	8.23i	19.33j	45.33h	34.90gh	10.63ef	2.31hi
	Herbicide appl.	85.22efg	371.67h	12.27cd	26.67c-f	73.00c	41.37b	11.40c	4.20c
	Hand pulling	83.34gh	403.67g	12.17d	28.67b-e	73.00c	41.07b	10.73def	3.85de
	Allelopathic weed management	81.23hi	378.00h	12.17d	26.67c-f	73.00c	38.39cd	10.87c-f	3.70e
135-90-50 kg ha^{-1}	No weeding	78.38ijk	219.0jk	9.43h	21.00hij	58.67f	37.69de	10.47f	3.01f
	Herbicide appl.	88.61a-d	511.67	13.03ab	31.33ab	86.00a	44.72a	12.40b	5.18a
	Hand pulling	86.85c-f	545.0a	13.13a	33.67a	89.67a	44.43a	12.23b	5.12a
	Allelopathic weed management	84.3fg	474.33cd	12.87ab	30.33abc	79.00b	41.36b	12.23b	4.73b
170-100-50 kg ha^{-1}	No weeding	80.07ij	196.67kl	8.63i	20.33ij	51.33g	35.76fg	11.03cde	2.66g
	Herbicide appl.	90.02ab	468.33cd	12.63bc	29.67a-d	79.00b	43.98a	13.10a	4.78b
	Hand pulling	87.98b-e	488.33c	12.63bc	28.67b-e	79.00b	43.52a	12.37b	4.65b
	Allelopathic weed management	85.78d-g	439.0ef	12.34cd	29.00b-e	73.00c	40.86b	13.00a	4.16c
205-110-50	No weeding	80.28i	160.0mn	11.03fg	23.33f-j	64.00de	33.82hi	11.23c	2.51gh
	Herbicideappl.	91.25a	428.67f	11.43ef	25.33d-h	64.00de	39.28c	13.30a	4.34c
	Hand pulling	89.61abc	455.67de	11.73e	26.00c-g	67.67d	38.76cd	13.10a	4.10cd
	Allelopathic weed management	86.39def	417.33fg	11.23f	24.67e-i	64.00de	36.47ef	13.23a	3.80e
S.E.		1.48	11.41	0.20	2.26	1.99	0.75	0.28	0.13
LSD at 0.05		3.01	23.11	0.41	4.57	4.02	1.51	0.56	0.26

Fertilizer rates (N-P-K) x weed management practices		Plant traits					
		Harvest index (%)	Leaf area (cm^2 $plant^{-1}$)	Leaf area index	LAD (days)	NAR ($g\ m^{-2}\ day^{-1}$)	CGR ($g\ m^{-2}\ day^{-1}$)
0-0-0 kg ha^{-1}	No weeding	19.73jk	215.10j	0.38 k	44.13i	2.60k	15.35l
	Herbicideappl.	21.03ij	247.17hi	0.71 ij	46.81hi	3.57ghi	18.55h-k
	Hand pulling	20.90ijk	279.47g	1.02 h	52.60ghi	3.33hij	18.89hij
	Allelopathic weed management	19.30k	245.57g	0.78 hi	52.16ghi	3.20ijk	17.75ijk
100-80-50 kg ha^{-1}	No weeding	21.67i	227.40 ij	0.45 jk	56.53gh	3.17ijk	16.59kl
	Herbicideappl.	36.77cd	301.00 d-g	1.59 efg	94.36cde	5.30bc	21.78def
	Hand pulling	35.87d	298.43 d-g	1.56 fg	87.60de	4.97cd	22.89b-e
	Allelopathic weed management	34.03e	282.50 fg	1.36 g	85.40de	3.93e-h	21.26efg
135-90-50 kg ha^{-1}	No weeding	28.87g	232.67hij	0.49 jk	71.10f	3.73f-i	17.33jk
	Herbicideappl.	41.80a	309.80cde	1.94 bcd	118.22a	6.200a	24.72ab
	Hand pulling	41.83a	304.40def	1.85 cde	109.33ab	5.80ab	25.38a
	Allelopathic weed management	38.63b	290.77 efg	1.58 efg	103.07bc	4.50de	24.15abc
170-100-50 kg ha^{-1}	No weeding	24.13h	245.57 hi	0.62 ijk	59.77g	3.50ghi	17.75ijk
	Herbicideappl.	36.50cd	319.07bcd	2.13 b	103.53bc	6.03a	23.33bcd
	Hand pulling	37.60bc	311.03cde	2.03 bcd	100.87bc	5.70ab	23.87abc
	Allelopathic weed management	31.90f	304.77def	1.79 def	86.53de	4.20ef	22.27cde
205-110-50 kg ha^{-1}	No weeding	22.33i	248.73 hi	0.68 ij	60.98fg	2.81jk	18.11ijk
	Herbicideappl.	32.57ef	337.17 ab	2.41 a	95.08cd	4.33ef	19.64ghi
	Hand pulling	31.20f	352.30 a	2.63 a	89.45de	4.01efg	20.18fgh
	Allelopathic weed management	28.70g	329.50 bc	2.11 bc	83.74e	3.50ghi	19.29hij
S.E.		0.85	11.38	0.14	5.29	0.29	0.97
LSD at 0.05		1.72	22.54	0.28	10.71	0.61	1.97

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Fertilizer rates (N-P-K) x weed management practicens		Plant traits						
		Weed control (%)	Wheat leaf nutrient concentration (%)			Wheat nutrient uptake (kg ha[1])		
			N	P	K	N	P	K
0-0-0 kg ha^{-1}	No weeding	0.00c	1.75h	0.12j	1.22i	59.85k	5.33f	41.09g
	Herbicideappl.	85.00a	2.71d-g	0.27ghi	3.63fgh	88.54ghi	8.01ef	51.84fg
	Hand pulling	78.67ab	2.78def	0.30g	3.50gh	99.13fgh	6.95ef	49.14fg
	Allelopathic weed management	69.00b	2.71d-g	0.28gh	3.36h	85.10hij	7.04ef	50.65fg
100-80-50 kg ha^{-1}	No weeding	0.00c	2.10gh	0.16ij	1.33i	69.13jk	7.84ef	58.00ef
	Herbicideappl.	85.0a	3.33cd	0.50def	4.08d-g	112.33def	20.36bcd	83.88c
	Hand pulling	79.00ab	3.09cde	0.43f	3.91e-h	108.77def	18.83cd	82.52cd
	Allelopathic weed management	69.00b	3.24cd	0.48ef	4.22c-f	104.27efg	17.57d	75.92cd
135-90-50 kg ha^{-1}	No weeding	0.00c	2.39fgh	0.22g-j	1.38i	81.88ij	9.40e	72.33cde
	Herbicideappl.	85.67a	4.47a	0.78a	5.0ab	143.46a	26.42a	126.34a
	Hand pulling	87.67ab	4.22ab	0.81a	4.75a-d	134.93abc	23.94ab	124.20a
	Allelopathic weed management	69.33b	4.57a	0.74a	5.10a	132.66abc	22.30bc	116.37ab
170-100-50 kg ha^{-1}	No weeding	0.00c	2.54efg	0.18hij	1.36i	77.70ij	9.33e	72.76cde
	Herbicideappl.	86.00a	4.52a	0.76a	4.98ab	136.63ab	26.34a	119.48ab
	Hand pulling	78.66ab	4.32ab	0.70ab	4.87abc	122.08bcd	23.87ab	116.79ab
	Allelopathic weed management	69.67b	3.72bc	0.61bcd	4.47a-e	118.37cde	22.25bc	111.78ab
205-110-50 kg ha^{-1}	No weeding	0.00c	2.34fgh	0.18hij	1.31i	77.68ij	9.32e	67.54de
	Herbicideappl.	85.66a	3.54c	0.70ab	4.33b-e	124.62bcd	26.28a	114.48ab
	Hand pulling	78.66ab	3.37cd	0.63bc	4.23c-f	113.96def	23.85ab	112.72ab
	Allelopathic weed management	69.67b	2.83def	0.57cde	3.88e-h	111.73def	22.04bc	106.69b
S.E.		5.27	0.33	0.06	0.34	8.28	1.78	7.57
LSD at 0.05		10.67	0.67	0.12	0.68	16.77	3.61	15.33

Correlations

The extent of relationship as depicted in (Figure 1a & b and Figure 2a-f) showed that wheat grain yield had positive relationship with LAD (r = 0.97), NAR (r = 0.88), leaf area index (r = 0.93), tillers m^{-2} (r = 0.94) and harvest index (r = 0.96), and according to (Figure 2d, e & f) there was positive relationship between biological yield and plant height (r =0.84), leaf area index and leaf area (r =0.95) as well as LAD and leaf area (r = 0.87).

The variation in wheat grain yield was due to its association with LAD (94%), NAR (77 %), LAI (86%), tillers m^{-2} (88%) and harvest index (93). Likewise, Variation in biological yield was due to its association with plant height (71%). The change in leaf area index was due to its connection with leaf area (89%), variation in LAD was due to its coalition with leaf area (76%).

Unit increase in various yield components of wheat correspondingly enhanced grain yield by LAD (0.05 t ha^{-1}), NAR (0.14 t ha^{-1}), LAI (1.45 t ha^{-1}), tillers m^{-2} (0.01 t ha^{-1}) and harvest index (0.14 t ha^{-1}) While, a unit increase in plant height resulted in correspondingly increased biological yield by 0.16 t ha^{-1}, whereas, a unit increase in LA improved LAI by 0.02 and LAD by 0.47 days.

The student Test was performed on those growth parameters of wheat which had showed correlations and the calculated T value was examined for grain yield vs LAI (18.67), grain yield vs tillers (20.45), grain yield vs harvest index (27.44), grain yield vs LAD (29.32), grain yield with NAR (13.79), biological yield vs plant height (11.90), LAI vs LA (22.17) and LAD vs LA (13.38). These T values were found higher than book value as calculated at 5% probability level which indicate that the correlations are highly significant.

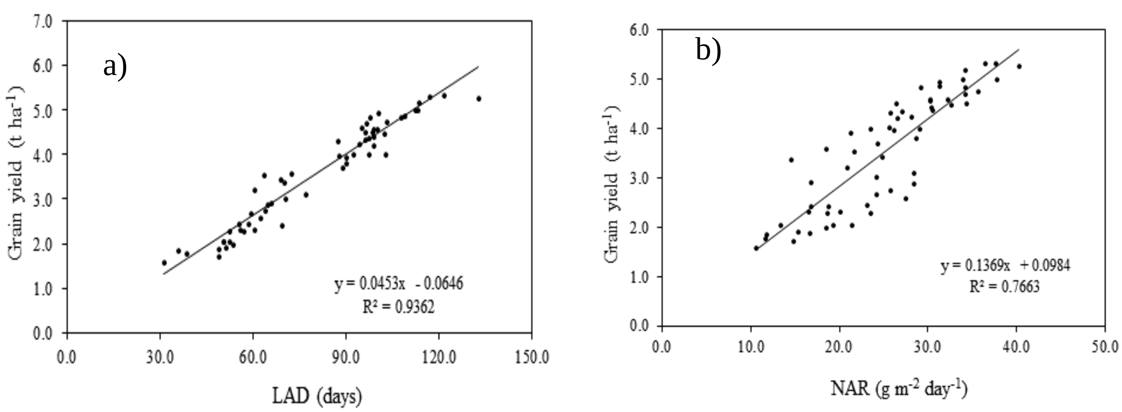

Figure 1. Linear regression between wheat grain yield and LAD (a) and NAR (b) as affected by NPK fertilizer and weed management practices

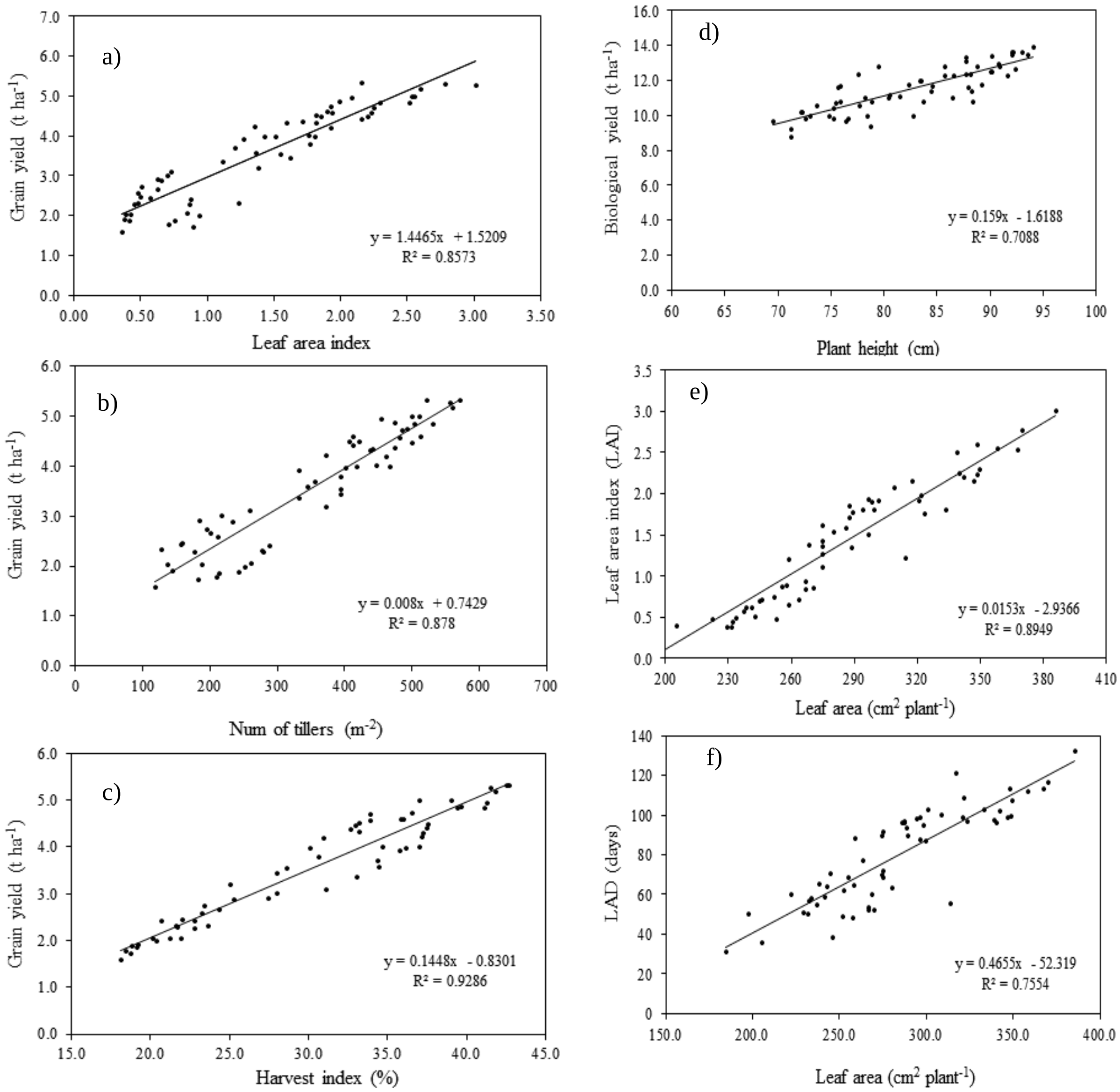

Figure 2. Linear regression between grain yield and LAI (a), grain yield and number of tillers m^{-2} (b) and grain yield and harvest index (c), while biological yield and plant height (d), leaf area and leaf area index (e) as well as LAD and leaf area (f) as affected by NPK fertilizer and weed management practices

Discussion

The results regarding agronomic characteristics of wheat such as plant height, tillers per unit area, spike length, spikelets spike^{-1}, grains spike^{-1}, seed index, biological yield, grain yield and harvest index, while the physiological traits like leaf area, leaf index, leaf area duration, net assimilation rate and crop growth rate as well as wheat leaf nutrient concentration (N, P and K%) and nutrient uptake (N, P and K kg ha^{-1}) were significantly affected by fertilizer rates, weed management practices and their interaction.

As regard to the effect of NPK fertilizer rates on agronomic characteristics of wheat, the higher fertilizer rate of 205-110-50 kg NPK ha^{-1} displayed higher plant height and biological yield and minimum values were presented in control plot. While, the medium fertilizer rate of 135-90-50 kg NPK ha^{-1} showed maximum tillers m^{-2}, spike length, spikelets spike^{-1}, grain spike^{-1}, seed index, grain yield and harvest index. It means that increasing fertilizer rates particularly N have increased vegetative growth and reduced reproductive growth as observed in higher biological yield that might be due to higher plant height. The other reason of lower reproductive growth at this higher fertilizer rates is might be due to higher weed density and weed biomass which competed more for light and nutrients than wheat crop. The higher grain yield on medium fertilizer rate is due to improvement in yield components like tillers m^{-2}, spike length, spikelets spike^{-1}, grains spike^{-1}, seed index and harvest index. Such association of yield and its components can be mirrored from linear regression analysis which revealed that grain yield was positively and significantly correlated with LAI, tillers m^{-2}, harvest index and NAR. Together with that some positive and significant correlation were also existed between biological yield vs plant height, LAI vs LA and LAD vs LA. These results are supported by Chauhan **[7]** who revealed that fertilizer rate of 120-60-40 NPK kg ha^{-1} increased the growth characteristics of wheat as compared to control where no fertilizer was applied. At this fertilizer rate maximum plant height of 92.4 cm was recorded that might be due to increased meristematic activity resulting in plant height enhancement. There was 33.3% higher grain yield and 35% straw yield over control plot. The higher fertilizer rates exhibited maximum biological yield which might be attributed to increased plant height.

All the studied physiological characteristics of wheat were observed higher at the medium fertilizer rate of 135-90-50 kg NPK ha^{-1} followed by the fertilizer rate of 170-100-50 kg NPK ha^{-1}. The higher fertilizer rate resulted in reduction of these physiological traits. However, their lowest values were noted in control plot. In this study, the higher wheat leaf N, P and K concentration and their uptake were recorded at the medium fertilizer rates of 135-90-50 and 170-100-50 kg NPK ha^{-1}. But the higher fertilizer rates resulted in reduction of nutrients concentration and uptake which might be due higher weed infestation as well as growth dilution effect. While control plot (zero fertilization) showed lower leaf N and K concentration as well as lower N, P and K uptake. Kalsoom *et al.* **[47]** reported that crop growth and dry matter is increased by the combined application of NPK rather than their alone application. Similar beneficial effect of chemical fertilizer on wheat was also observed by Sandhya *et al.* **[48]**.

The wheat physiological characteristics such as leaf area, LAI, LAD, NAR and CGR were significantly affected by weed management practices. The maximum leaf area (cm^{2} plant^{-1}), leaf area index, LAD (days), NAR (g m^{-2} day^{-1}) and CGR (g m^{-2} day^{-1}) were examined in plot when weed were controlled by herbicides application with closely followed by hand pulling method of weed control. As compared to no weeding, the allelopathic weed control also resulted in increasing physiological traits of wheat but were less effective as compared to herbicides application and hand pulling weed control. This increase in physiological traits might be due to reduction of competition between wheat and weeds for space, moisture, nutrients and light because weeds are one of the important constraints for sustainable yield production of most crops particularly of wheat. Similar effect of weeds control on wheat physiological characteristics were reported by Mubeen *et al.* **[49]** who observed maximum leaf area index and leaf area duration of rice in chemically weed control plot (penoxsulam or bispyribac-sodium) followed by hand-hoeing. Similarly, Iqbal and Wright **[50]** reported that increasing weed density resulted in lower wheat net assimilation rate. The effects of weed infestation on rice growth indices such as LAI, CGR and LAD were studied by Ashraf *et al.* **[51]**. They recorded higher LAI, CGR and LAD of rice crop in weed free plot while weed infestation resulted in reduction of these growth indices of rice. Same results were also reported by Islam *et al.* **[52]** who observed maximum CGR of crop when there was less crop weed competition and where resources were adequate. Girma **[53]** revealed that LAI and CGR were decreased by 61-75% due to competition of wild mustard. Similar results were reported by Fischer **[54]** who indicated that a decrease in CGR of wheat related with a simultaneous decline in light interception.

As regard to the interactive effect of fertilizer rates x weed management practices, the result revealed significantly higher plant height in the interactive effect of fertilizer rate of 205-110-50 kg NPK ha^{-1} x weed control by herbicides application while higher biological yield was noted at same fertilizer with three weed management of W2, W3 and W4. The other agronomic traits like tillers m^{-2}, spike length, spikelets $spike^{-1}$, grains $spike^{-1}$, seed index, grain yield and harvest index manifested higher values at the interaction of fertilizer rate (135-90-50 kg NPK ha^{-1}) x W2 and W3. In contrast, the weed infested plot (control) with and without fertilizer application suppressed all these traits. Similar interaction was reported by Pourreza *et al.* **[55]** who examined significant effect of wild oat densities, N rates and the interaction of wild oat density x N rates on wheat grain yield. They found maximum (400.3 g m^{-2}) wheat grain yield at the interactive effect of N rate (50 N kg ha^{-1} pre-sowing time + 100 N kg ha^{-1} at late tillering) x zero wild oat density. The interactive effect of higher N rate (150 N kg ha^{-1} at pre seeding) x higher wild oat density (100 seeds m^{-2}) produced lower (173.3 g m^{-2}) wheat grain yield. These results are in accordance with Sary *et al.* **[56]** who noted that the interactive effect of herbicides application x fertilizer rate (25% bio-organic and 75% recommended NPK) had good impact on reduction of weeds at 75 days after sowing. But after 105 DAS, the interactive of herbicide application x 100% recommended NPK was most effective against weeds. They revealed that the interactive effect of herbicide application x recommended NPK fertilizer produced higher number of tillers m^{-2}, number of spikes m^{-2}, biological and grain yield.

As regard to the interactive effect of fertilizer rate x weed management, the higher N, P and K concentration and uptake was recorded in the interaction of medium fertilizer rate of 135-90-50 kg NPK ha^{-1} with W2, W3 and W4 while, weed infested plot (weedy check) resulted in reduced wheat leaf N, P and K concentration and uptake on all fertilizer rates. Similar results were reported by Sary *et al.* **[56]** who recorded higher P and K uptake of wheat at the interactive effect of hand weeding x fertilizer rate (25% recommended bio-organic fertilizer + 75% recommended NPK fertilizer). Similar results were observed by Singh **[57]** that NPK application and weed control by Pendimethalin manifested useful impact on overall growth of wheat and increased grain yield.

Conclusion

From this study, it is inferred that the manipulation of fertilizer rates and weed management practices manifested significant variations on wheat traits. It was evidenced that agronomic and physiological traits of wheat along with nutrient accumulation and uptake were increased when wheat crop was supplied with 135-90-50 NPK kg ha^{-1} and weed were controlled by herbicide application and hand hoeing. Consequently, these practices minimized weed crop competition and recorded higher wheat yield. The linear regression analysis between yield and yield components under the influence of different fertilizer rates and weed management practices were positive and significant which rectifies that enhancement in yield was due to the increase of all agronomic and physiological characteristics and higher nutrient uptake.

Authors' contributions

Conceived and designed the experiments: MA Babar, Performed the experiments: S Azam, Analyzed the data: A Jan & A Khan, Contributed materials/ analysis/ tools: S Azam & Ikramullah, Wrote the paper: MA Baber & M Arif.

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