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VEGETATION SURVEY AND RESTORATION OF ECOSYSTEMS

Wheat (*Triticum aestivum*) yield gap affected by soil physicochemical properties

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Abstract

Due to the important process of global warming, the improvement of soil factors, which decrease wheat (*Triticum aestivum* L.) yield gap, in the arid and semi-arid areas of the world including Iran (Kerman province) is of significance. The objective was to determine how wheat yield gap and yield components, in 15 different fields (three different locations with areas ranging from 2993 to 5175 km^2), are affected by soil physicochemical properties including texture, electrical conductivity (EC), pH, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P) and potassium (K), and chemical fertilization. Wheat yield components including tiller and grain number, fertile spike, spike length, 1000-grain weight (25–44 g), plant height, biological yield (plant dry weight) (4880–14800 kg/ha), and plant density were measured. Linear regression analyses indicated that SOC (0.23–1.51%), TN (0.02–0.15%) and available K (195–280 mg/kg) significantly affected wheat yield and yield components, which were also positively and significantly correlated. There was a positive and significant correlation between SOC, TN, and available P and K, which were negatively and significantly correlated with EC. The regression models relating soil physicochemical properties with spike length and plant height were significant ($P \leq 0.05$). The R^2 values ranged from 0.54 (number of grains per spike) to 0.90 (plant height) and for economic (grain) and biological yields were equal to 0.75 and 0.83, respectively. The yield gap was in the range of 1245–4256 kg/ha. The improvement of soil physicochemical properties may decrease wheat yield gap in the arid and semi-arid areas of the world.

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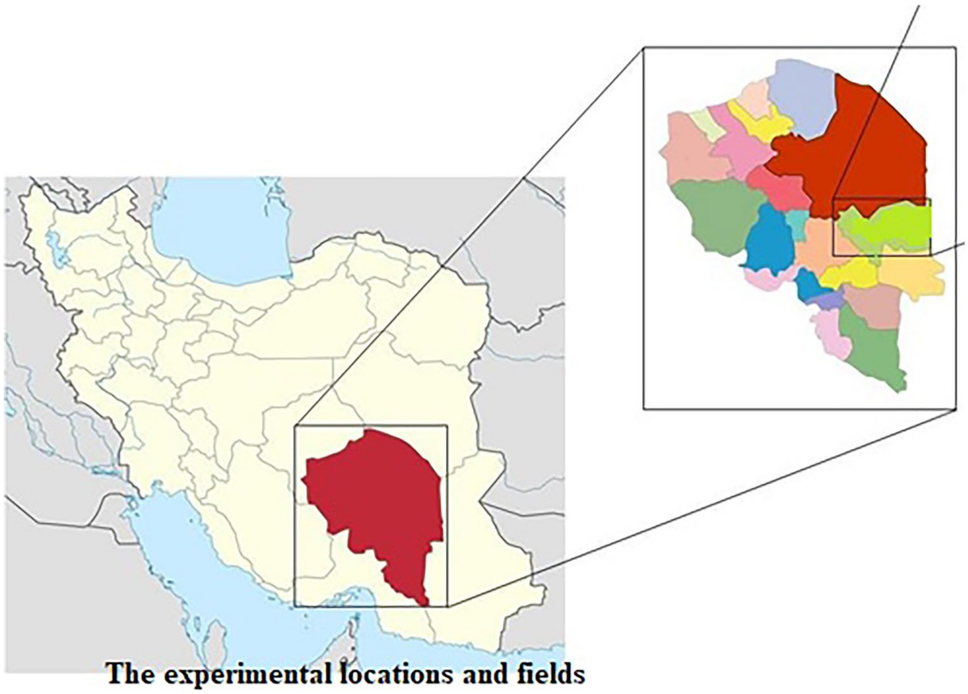
Graphic abstract



Keywords Correlation coefficients · Global warming · Soil nutrients · Soil organic carbon · Total N · Regression analyses · Wheat (*Triticum aestivum* L.) · Yield gap

1 Introduction

Food production for the world increasing population is one of the most important challenges of the 21st century. Different methods have been used to enhance yield production per hectare such as the use of chemical and biological fertilization, breeding methods, and efficient irrigation methods (Tadesse et al. 2019; Kazemi et al. 2022). Wheat is among the most important cereal crops providing 55% of carbohydrate and 20% of calories and proteins for the people, worldwide (Jat et al. 2018; Firouzian et al. 2023).

However, one important issue, which has to be more investigated, is to decrease the yield gap by finding and improving the yield limiting parameters (Yang et al. 2023) in the arid and semi-arid areas of the world including Iran. Soil physicochemical properties are among the most important parameters affecting the potential yield production of different crop plants including wheat (*Triticum aestivum* L.). Finding and improving such parameters can help the farmers decrease the gap between the real and the potential yield (Di Mauro et al. 2018; Hajjarpoor et al. 2018; Nehbandani et al. 2021). Di Mauro et al. (2018) investigated the limiting factors such as fertilization, moisture and rotation, which may affect soybean yield gap in Argentina and Nehbandani et al. (2021) determined soyabean yield gap in Iran using soybeans simulation model and GIS.

Moharana et al. (2020) investigated the yield limiting factors affecting yield production in the irrigated field of arid areas in India. They analysed soil samples for pH, soil organic carbon (SOC), salinity (EC), and macro- and micronutrients including nitrogen (N), phosphorous (P), potassium (K), iron, manganese, zinc and copper. Although soil nutrients were highly variable, their recommendations on the basis of soil test and crop response significantly decreased fertilizer use and environmental pollution and maximized yield production.

Cao et al. (2019) investigated the potential yield of wheat plants, and the limiting factors, which may affect the yield gap. They analysed the data to indicate the yield gap contribution of spikes per hectare, weight of 1000 grains, and grain number per spike to the production of wheat yield. The results indicated that while the wheat potential yield was equal to 10,514 kg ha^{-1}, the yield gap was in the range of 814–2493 kg ha^{-1}. Among the measured yield components, spikes per hectare were the most important factor significantly affecting wheat yield. They also indicated that spikes per hectare were most affected by seedling date (26.7%), basal N input (22.1%) and seedling rate (14.5%). The desired

N fertilization for the optimum production of spikes per hectare was in the range of 90–180 kg ha^{-1}.

The soil factors of texture, salinity, pH, SOC, total nitrogen (TN), available P and K, analysed in the present research are among the most important parameters significantly affecting wheat yield production, worldwide. Soil texture affects different soil behavior such as the absorption of water and nutrients, and colloidal responses including cation exchange capacity, etc.(Ouyang et al. 2023). Salinity is also an important factor affecting wheat yield and nutrient uptake, especially in the arid (saline) areas of the world. SOC provides the carbon essential for plant growth and microbial activities and affects the structure of the soil. The three important macro-nutrients of N, P and K can significantly contribute to the increased production of crop yield as they are essential for different plant physiological processes (Farmaha et al. 2016; Liu et al. 2016; Schils et al. 2018).

With respect to the above-mentioned details, it is accordingly important to highlight the role of each soil factor in determining wheat yield gap in the arid and semi-arid areas of the world to decrease the gap by increasing wheat yield production. Although there has been research on the role of different parameters affecting the wheat yield gap in the arid and semi-arid areas, more has yet to be investigated on the effects of soil factors affecting wheat yield production in such areas. Accordingly, the objective of the present research was to determine the effect of soil physicochemical factors on the yield gap of wheat plants in the province of Kerman, Iran.

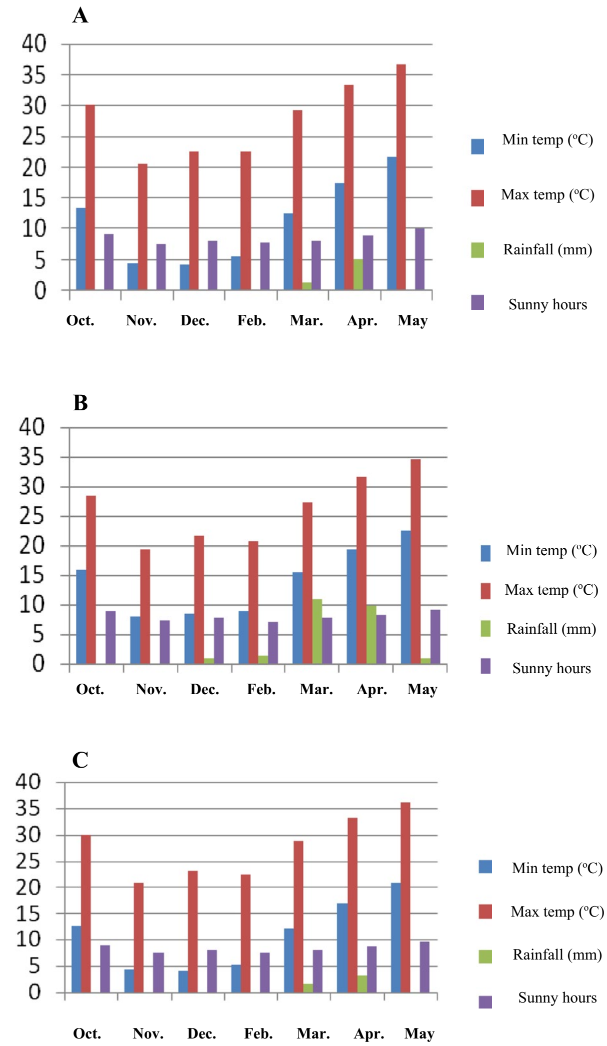


Fig. 1 The yearly average of minimum and maximum temperatures, rainfall and sunny hours for (A) Bam, (B) Narmashir, and (C) Fahraj

2 Materials and methods

2.1 Experimental locations

The research was conducted in three different locations of Bam, Narmashir, and Fahraj, province of Kerman, Iran. Bam has an area of 5175 km^2 with the northern longitude of 58° 21′ 25″ and the eastern latitude of 29° 6′ 22″, 1061 m above the sea level. The region has a yearly rainfall of 54 mm, average temperature of 23.5 °C, and maximum and minimum temperatures of 47.6 and – 8.6 °C, respectively. Narmashir with an area of 2993 km^2, is located in the northern longitude of 58° 42′ 12″ and eastern latitude of 28° 57′ 7″, with the altitude of 757 m. The region has a yearly rainfall of 43 mm, average temperature of 24 °C, and maximum and minimum temperatures of 47.8 and – 2.8 °C, respectively. Fahraj with the area of 4558 km^2, northern longitude of 58° 53′ 23″ and eastern latitude of 28° 56′ 54″, is located 670 m above the sea level. The yearly rainfall in the region is 38 mm, with the average temperature of 25.2 °C, and maximum and minimum temperatures of 49.2 and – 6.6 °C (Figs. 1 and 2).

2.2 The experiment

The experiment was conducted in 2017–2018, by randomly selecting 15 different wheat fields cultivated with the Roshan genotype. The experimental details related to the soil, agronomical practices, climate, and crop traits of the fields were collected. Soil physicochemical properties (0–30 cm) including EC, pH, organic carbon (C), total nitrogen (N) (Kjeldahl method), available phosphorous (P) (Olsen method using ascorbic acid) and potassium (K) (using flame photometer), and clay, silt and sand were determined using the standard methods (Miransari et al. 2008).

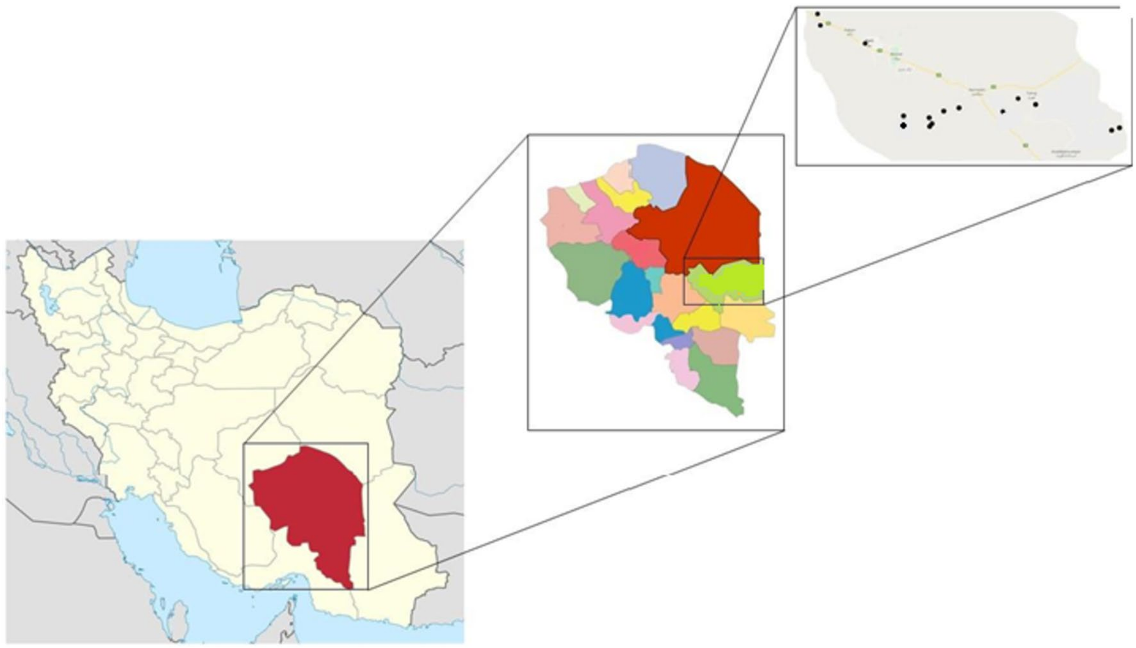


Fig. 2 The experimental locations and fields

2.3 Wheat genotype

The Roshan genotype is one of the oldest ones, selected from among different genotypes planted in Isfahan province, Iran. The genotype is recommendable for regions with mild and warm climates, and is planted in spring and autumn, with 1000-grain weight of 45 g, yield of 4 T/ha, and the plant height of 100–115 cm. The optimum plant density/m^2 is 400–450, achieved by planting 160–180 kg/ha seed, the suitable planting date is from October to November, and the harvesting time is June. The grains are yellow, and the plant is semi early-maturing type and tolerant to drought and salinity.

2.4 Measurements

The agronomical practices in the region include preparation of the field (disk, dry and wet farming), time and method of planting, time and amounts of NPK fertilization, controlling weeds, pests and diseases, method of irrigation, and time and method of harvesting. The climatic data including minimum and maximum temperatures, daily sunlight, and the amount of rainfall were also collected. The crop traits (30 samples for each field) including number of tillers per plant, plant height, number of fertile spike/m^2, length of spike, weight of 1000 grains (taking 10 samples of 100 grains with the moisture of 12%), biological and economic (grain) yields were also collected. The yield gap, which is difference between actual yield and potential (maximum) yield, was calculated using the following formula:

$$\text{Yield gap} = (\text{potential yield} - \text{real yield}) / \text{real yield} = n * 100$$

2.5 Statistical analyses

Data were subjected to “t” and regression analyses using SAS. The correlation coefficients among the measured parameters were also determined. The regression graphs were plotted using SAS Proc Plot.

3 Results

3.1 “t” analyses

According to “t” analysis, SOC significantly affected wheat yield and yield components including yield, yield gap, number of fertile spikes, spike length, and plant dry weight (biological yield). The effects of TN were significant on crop yield and yield gap, number of tillers, spike length, and plant dry weight. Available K also significantly affected wheat yield and gap, number of tillers, spike length, weight of 1000 grains, plant height and plant dry weight (Table 1).

3.2 Plant factors

According to Table 2, mean wheat yield was equal to 3550 $kgha^{-1}$ with the minimum and maximum values of 1116 and 6272 $kgha^{-1}$, respectively. The corresponding values for the number of tillers were equal to 4, 2 and 6, respectively. The

Table 1 The t analyses indicating the significance of each variable on the measured parameters in the linear regression model

	Yield	Yield1	Yield2	Tillers	Fertile spike	Number of grains	Spike length	Weight of 1000 grains	Plant height	Plant dry weight	Plant density
Variable	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|	Pr>|t|
Intercept	0.2726	0.5783	0.5378	0.8999	0.1194	0.6117	0.6918	0.4928	0.4194	0.2546	0.4732
Tex	0.1453	0.4097	0.1453	0.0272	0.4510	0.4016	0.0737	0.2239	0.0214	0.0845	0.0815
EC	0.4290	0.4077	0.4289	0.7980	0.7231	0.3252	0.1596	0.7875	0.8967	0.3924	0.9716
pH	0.7254	0.6095	0.7253	0.2010	0.6249	0.6509	0.0704	0.3858	0.1635	0.4999	0.2364
SOC	0.0247*	0.1477	0.0247*	0.0552	0.0495*	0.4880	0.0347*	0.0991	0.0533	0.0130*	0.2810
TN	0.0215*	0.1058	0.0215*	0.0306*	0.0682	0.4179	0.0195*	0.0726	0.0206*	0.0100*	0.1831
Avail P	0.7561	0.4100	0.7562	0.7033	0.6467	0.7194	0.6602	0.3881	0.1259	0.6837	0.9202
Avail K	0.0462*	0.0319*	0.0462*	0.0220*	0.4434	0.3514	0.0279*	0.0371*	0.0039**	0.0177*	0.0955
Fertilization	0.5981	0.5265	0.5982	0.2117	0.5985	0.6908	0.3532	0.2771	0.4520	0.5279	0.4607

Yield 1&2: yield gap 1 and 2, *Tex*: texture, *EC* salinity, *SOC* soil organic carbon, *TN* total N, Avail P and K: available P and K

Table 2 The mean (± SD), the minimum and maximum values of the measured plant and soil factors

Variable	Mean ± SD	Minimum	Maximum
Y	3550 ± 1268	1116	6272
till	4 ± 1.41	2	6
Fertile	381.87 ± 43.84	324	476
G	25.93 ± 5.69	10	35
L	6.95 ± 0.89	5	8.5
W	35.07 ± 5.74	25	44
H	78.73 ± 15.08	55	95
PDW	9136 ± 2833	4880	14,800
PD	119.76 ± 42.05	60	192
EC	3.50 ± 0.65	2.06	4.32
pH	7.56 ± 0.21	7.03	7.86
SOC	0.88 ± 0.34	0.23	1.51
TN	0.09 ± 0.04	0.02	0.15
AvailP	7.45 ± 1.46	4.72	9.3
AvailK	235 ± 30	195	280
Fert	140.53 ± 59.94	50	300

Y yield, *till* number of tillers, *Fertile* number of fertile spike, *G* number of grains, *L* spike length, *W* weight of 1000 grains, H: plant height, PDW: plant dry weight (biological yield), *PD* plant density, *EC* salinity, *SOC* soil organic carbon, *TN* soil total nitrogen, *AvailP* available P, *AvailK* available K, *Fert* fertilization

mean number of fertile spikes was 382, with the minimum and maximum of 324 and 476, respectively. The number of grains per spike was in the range of 10–35 with the mean value of 26. The length of spike ranged from 5 to 8.5 cm with the mean of 6.95 cm. The weight of 1000 grains, was equal to 35.07 g ranging from 25 to 44 g. Plant height averaged 78.73 cm ranging from 55 to 95 cm. Plant dry weight (biological yield) had the mean value of 9136 $kgha^{-1}$, with the minimum and maximum values of 4880 and 14,800 $kgha^{-1}$, respectively. The mean of plant density was equal to 120 and ranged from 60 to 192 (Table 2).

3.3 Soil factors

The soil textures were loamy, clayey, clay loamy, silty loamy, silty clay loamy, and sandy clay loamy. The average EC was equal to 3.5 dSm^{-1}, ranging from 2.06 to 4.32 dSm^{-1}. Soil pH was in the range of 7.03–7.86, with the mean value of 7.56. The mean of SOC was equal to 0.88%, with the minimum and maximum values of 0.23 and 1.51%, respectively. The mean value of total N was equal to 0.09% ranging from 0.02 to 0.15%. Available P ranged from 4.72 to 9.3 $mgkg^{-1}$, with the mean value of 7.45 $mgkg^{-1}$. The mean value of K was 235 $mgkg^{-1}$ ranging from 195 to 280 $mgkg^{-1}$. Chemical fertilization had the mean value of 140 $kgha^{-1}$ ranging from 50 to 300 $kgha^{-1}$ (Table 2).

3.4 Correlation coefficients

The correlation coefficients indicated that wheat yield was positively and significantly correlated with chemical fertilization and with all the yield components expect plant density. Number of tillers was also positively and significantly correlated with yield and all the yield components excluding number of fertile spikes. However, the correlation between the number of tillers and plant density was significant and negative. Number of fertile spikes was just positively and significantly correlated with crop yield and plant dry weight. There was a positive and significant correlation between number of grains with yield, number of tillers, spike length, plant height, plant dry weight and chemical fertilization (Table 3).

Spike length was positively and significantly correlated with soil total N, and with yield and all yield components, except number of fertile spike and weight of 1000 grains; however, it was negatively and significantly related with plant density. There was a positive and significant correlation between weight of 1000 grains with yield and yield gap, plant height and plan dry weight; and its correlation with with plant density was negatively significant (Table 3).

Plant height was positively and significantly correlated with chemical fertilization, and with yield and all yield components except number of fertile spikes; however, its correlation with plant density was negative and significant. Plant dry weight was positively and significantly correlated with fertilization, yield and all yield components, and it was negatively and significantly correlated with plant density. Plant density was negatively and significantly correlated with yield gap, spike length, weight of 1000 grains, plant height, and plant dry weight (Table 3).

Among the soil factors, EC was negatively and significantly correlated with SOC, total N, and available P. The correlation between SOC and EC was negative and significant; however, the correlation of SOC with TN, available P and K was positive and significant. Total N and plant height, SOC and available P and K were positively and significantly correlated and they were negatively and significantly correlated with salinity (Table 3).

Available P was positively and significantly correlated with SOC, TN and available K, and it was negatively and significantly correlated with soil EC. However, available K was just positively and significantly correlated with SOC, TN and available P. Chemical fertilization was positively and significantly correlated with wheat yield, number of grains, plant height and plant dry weight (Table 3).

3.5 Regression analyses

The linear regression analyses examined the effects of all soil factors on yield and yield components. According to the analyses, the determination coefficients for wheat yield with soil factors, was equal to 0.75 (Fig. 3). For the yield components the determination coefficients were according to the following: yield gap: 0.75 (Fig. 4), number of tillers: 0.79 (Fig. 5), spike length: 0.85 (Fig. 6), plant height: 0.90 (Fig. 7), and plant dry weight: 0.83 (Fig. 8). The regression models relating soil physicochemical properties with spike length and plant height were significant at $P \leq 0.05$.

4 Discussion

Due to the world increasing population and the limitation of resources for food production, finding and improving the soil factors, which increase wheat yield production is of significance. The effects of different soil physicochemical properties including texture, EC, pH, SOC, TN, available P and K, and chemical fertilization on the gap of wheat yield in the arid area of Kerman province, Iran were investigated.

According to the results, SOC, Total N, and available K, were the soil factors, which significantly affected wheat yield and yield components. SOC is among the most important factors significantly affecting soil characteristics and yield production. However, in the arid and semi-arid areas of the world, due to the deficiency of moisture and plant cover, the rate of SOC is not high (Shokuhifar et al. 2023), which is similar to the results of the present research. Accordingly, the amount of SOC was less than the required amount (usually 2%) in the experimental fields indicating the need for the restoration of SOC in such fields using different sources of organic matter such as crop residues, livestock manure, etc. Increasing SOC would significantly decrease the gap of wheat yield in the tested fields by contributing to higher wheat yield production. Elias et al. (2019) also found similar results as SOC was among the most important soil factors significantly affecting wheat yield production in the highlands of Ethiopia explaining 28% of yield variation. The table of correlations (Table 3) also indicated there was a positive correlation between wheat yield and SOC, although not significant indicating that higher amounts of SOC are required for wheat production in such fields.

TN was the other important factor, which significantly affected wheat yield production in the experimental fields, which is also similar to the results of Elias et al. (2019). Nitrogen is among the most important factors required for a wide range of plant physiological processes including photosynthesis, enzymatic structure and activities, etc., which eventually results in filling crop grains, and yield production (AL-Huqail et al. 2022). According to our results, the level of TN in the tested fields was not high, and more N must be supplied to provide wheat plants with their optimum N using a combination of chemical and organic N fertilization (Li et al. 2018).

Table 3 The correlation coefficients among different tiled components and soil parameters

	Y	till	Fertile	G	L	W	H	PDW	PD	Tex	EC	pH	SOC	TN	AvailP	AvailK	Fert
Y	1	0.66018**	0.57055*	0.77827**	0.62811*	0.79719**	0.71957**	0.9782**	− 0.4423	− 0.04937	− 0.21369	0.09254	0.21715	0.29403	0.15037	− 0.03043	0.52379*
till	0.66018**	1	0.05991	0.59495**	0.75223**	0.65138**	0.80728**	0.7298**	− 0.92287**	− 0.36651	0.06568	0.36676	0.28693	0.31963	0.11313	0	0.43817
Fertile	0.57055*	0.05991	1	0.09449	0.17702	0.3652	0.10757	0.53403*	0.20544	0.02498	− 0.16047	0.02657	− 0.07449	0.03861	0.13221	0.15973	0.13007
G	0.77827**	0.59495*	0.09449	1	0.57167*	0.42254	0.56112*	0.71375**	− 0.47792	− 0.15608	− 0.27995	0.0497	0.28479	0.30774	0.09369	− 0.04882	0.54651*
L	0.62811*	0.75223**	0.17702	0.57167*	1	0.50498	0.68141**	0.70317**	− 0.69932**	− 0.14455	− 0.33531	0.3209	0.51266	0.57328*	0.26068	0.24248	0.42007
W	0.79719**	0.65138**	0.3652	0.42254	0.50498	1	0.85471**	0.85687**	− 0.52687*	− 0.01899	− 0.05436	0.15441	0.18495	0.21555	0.15194	− 0.17675	0.38161
H	0.71957**	0.80728**	0.10757	0.56112*	0.68141**	0.85471**	1	0.80856**	− 0.74642**	− 0.20643	− 0.07867	0.18891	0.4238	0.43047	0.28523	− 0.1081	0.62247*
PDW	0.9782**	0.7298**	0.53403*	0.71375**	0.70317**	0.85687**	0.80856**	1	− 0.52665*	− 0.06089	− 0.19736	0.13203	0.2631	0.33484	0.16475	− 0.04729	0.57497*
PD	− 0.4423	− 0.92287**	0.20544	− 0.47792	− 0.69932**	− 0.52687*	− 0.74642**	− 0.52665*	1	0.41511	− 0.07862	− 0.37906	− 0.23798	− 0.25089	− 0.06488	0.02621	− 0.4061
Tex	− 0.04937	− 0.36651	0.02498	− 0.15608	− 0.14455	− 0.01899	− 0.20643	− 0.06089	0.41511	1	− 0.16464	− 0.27686	0.05321	0.06875	0.00719	− 0.14153	− 0.17419
EC	− 0.21369	0.06568	− 0.16047	− 0.27995	− 0.33531	− 0.05436	− 0.07867	− 0.19736	− 0.07862	− 0.16464	1	0.34409	− 0.61339*	− 0.6201*	− 0.53039*	− 0.47665	0.08271
pH	0.09254	0.36676	0.02657	0.0497	0.3209	0.15441	0.18891	0.13203	− 0.37906	− 0.27686	0.34409	1	− 0.06587	− 0.0055	0.07207	0.24594	0.15826
SOC	0.21715	0.28693	− 0.07449	0.28479	0.51266	0.18495	0.4238	0.2631	− 0.23798	0.05321	− 0.61339*	− 0.06587	1	0.98584**	0.6267*	0.62376*	0.06764
TN	0.29403	0.31963	0.03861	0.30774	0.57328*	0.21555	0.43047	0.33484	− 0.25089	0.06875	− 0.6201*	− 0.0055	0.98584**	1	0.64959**	0.68765**	0.09753
AvailP	0.15037	0.11313	0.13221	0.09369	0.26068	0.15194	0.28523	0.16475	− 0.06488	0.00719	− 0.53039*	0.07207	0.6267*	0.64959**	1	0.61274*	0.06089
AvailK	− 0.03043	0	0.15973	− 0.04882	0.24248	− 0.17675	− 0.1081	− 0.04729	0.02621	− 0.14153	− 0.47665	0.24594	0.62376*	0.68765**	0.61274*	1	− 0.27072
Fert	0.52379*	0.43817	0.13007	0.54651*	0.42007	0.38161	0.62247*	0.57497*	− 0.4061	− 0.17419	0.08271	0.15826	0.06764	0.09753	0.06089	− 0.27072	1

Y yield, till: number of tillers, *Fertile* number of fertile spike, *G* number of grains, *L* spike length, *W* weight of 1000 grains, *H* plant height, *PDW* plant dry weight (biological yield), *PD* plant density, *Tex* soil texture, *EC* salinity, *SOC* soil organic carbon, *TN* soil total nitrogen, *AvailP* available P, *AvailK* available K, *Fert* fertilization

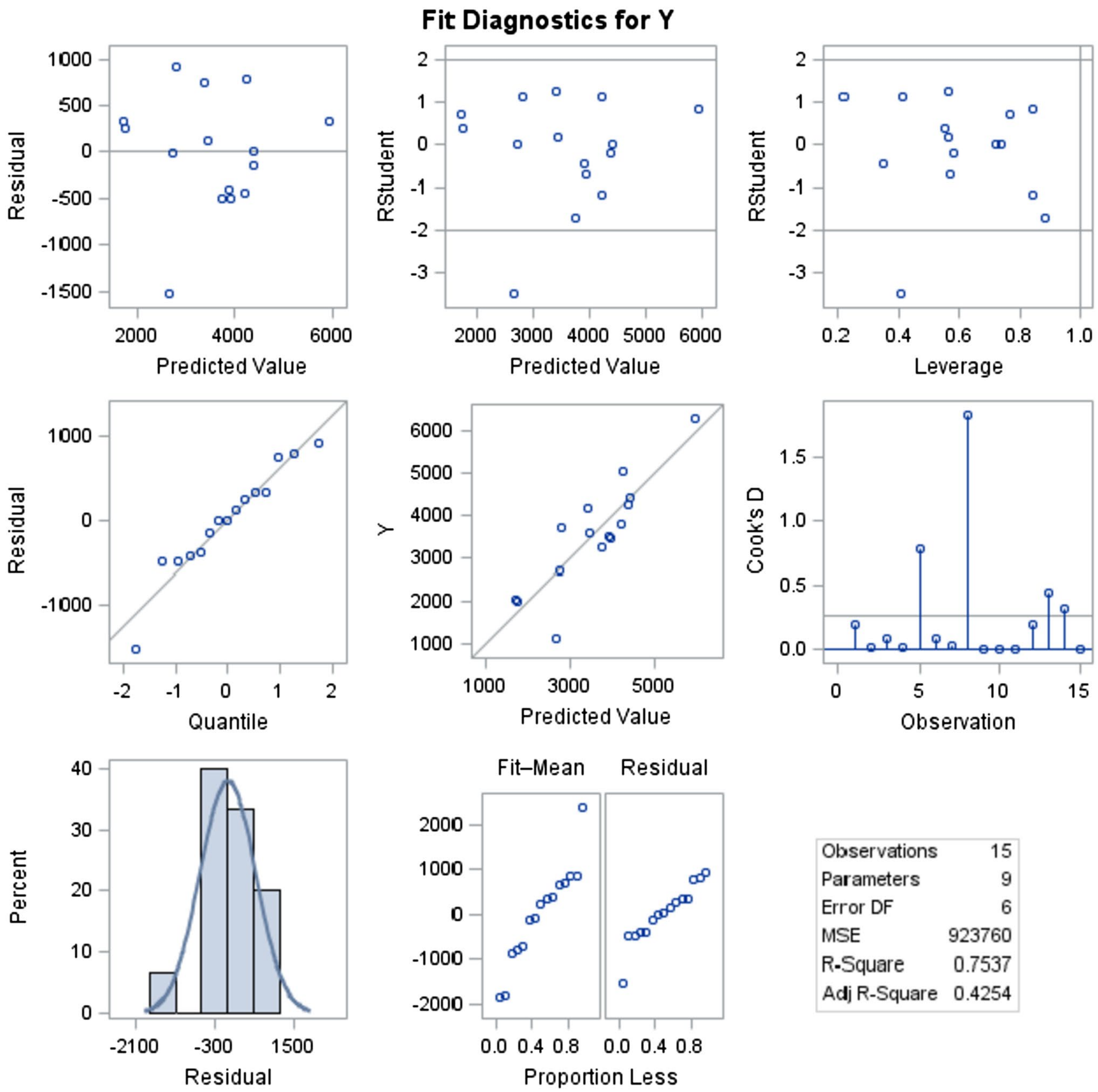


Fig. 3 The fit analyses of wheat yield affected by the experimental parameters in the linear regression model

Soil potassium was also among the factors, which significantly affected wheat yield and yield components. Potassium is an important macro-nutrient controlling different plant metabolic activities such as the activities of enzymes, plant water behavior, etc. (Sardar et al. 2023). Compared with soil P, the availability and solubility of K in the soil is much higher, and hence it is more available for plant use (Shahabifar et al. 2019; Song et al. 2020). According to the results, although optimum amounts of K were available in the tested fields, the latter can be yet responsive to the use of K fertilization for the production of higher yield.

Wheat yield was in the range of 1116–6272 kgha^{-1} with the average of 3550 kgha^{-1} indicating a yield gap of 1245–4256 kgha^{-1}. If wheat plants in the experimental regions are supplied with optimum amounts of organic matter including manure, biochar, crop residues, etc. and macronutrients, especially N and K, it would be possible to increase wheat in the tested regions and similar regions, worldwide, and decrease the yield gap to the least amount.

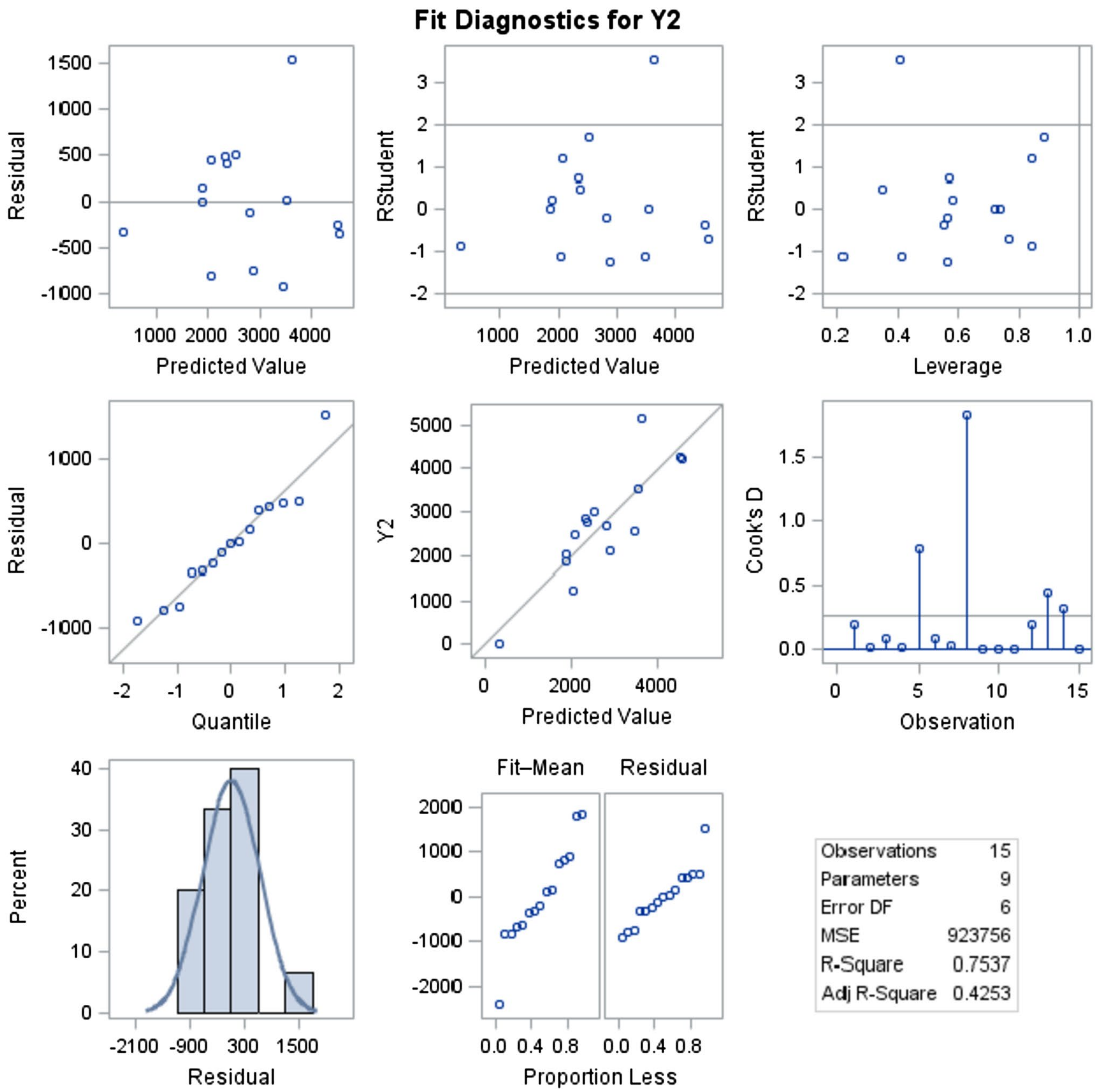


Fig. 4 The fit analyses of wheat yield gap affected by the experimental parameters in the linear regression model

Hawes et al. (2018) also indicated the increase in SOC, pH and macronutrients may: (1) decrease wheat yield gap, (2) increase biodiversity, and (3) reduce soil pollution. Plant dry matter (biological yield) was also among the most affected yield components by the soil factors, with a high and significant correlation with wheat yield (0.98**). This indicates that biological yield, which was positively affected by soil physicochemical parameters, can also be used as an indicator of wheat yield production in the arid- and semi-arid areas of the world, (Woźniak 2019).

Although there was positive correlation between the soil factors and yield components, the highest and the most significant correlations were found among wheat yield and yield components. Number of tillers, number of fertile spikes, spike length, and plant height were among the plant components, which were affected the most by the tested soil factors. Accordingly, the contribution of each component can significantly affect wheat yield production in the tested regions.

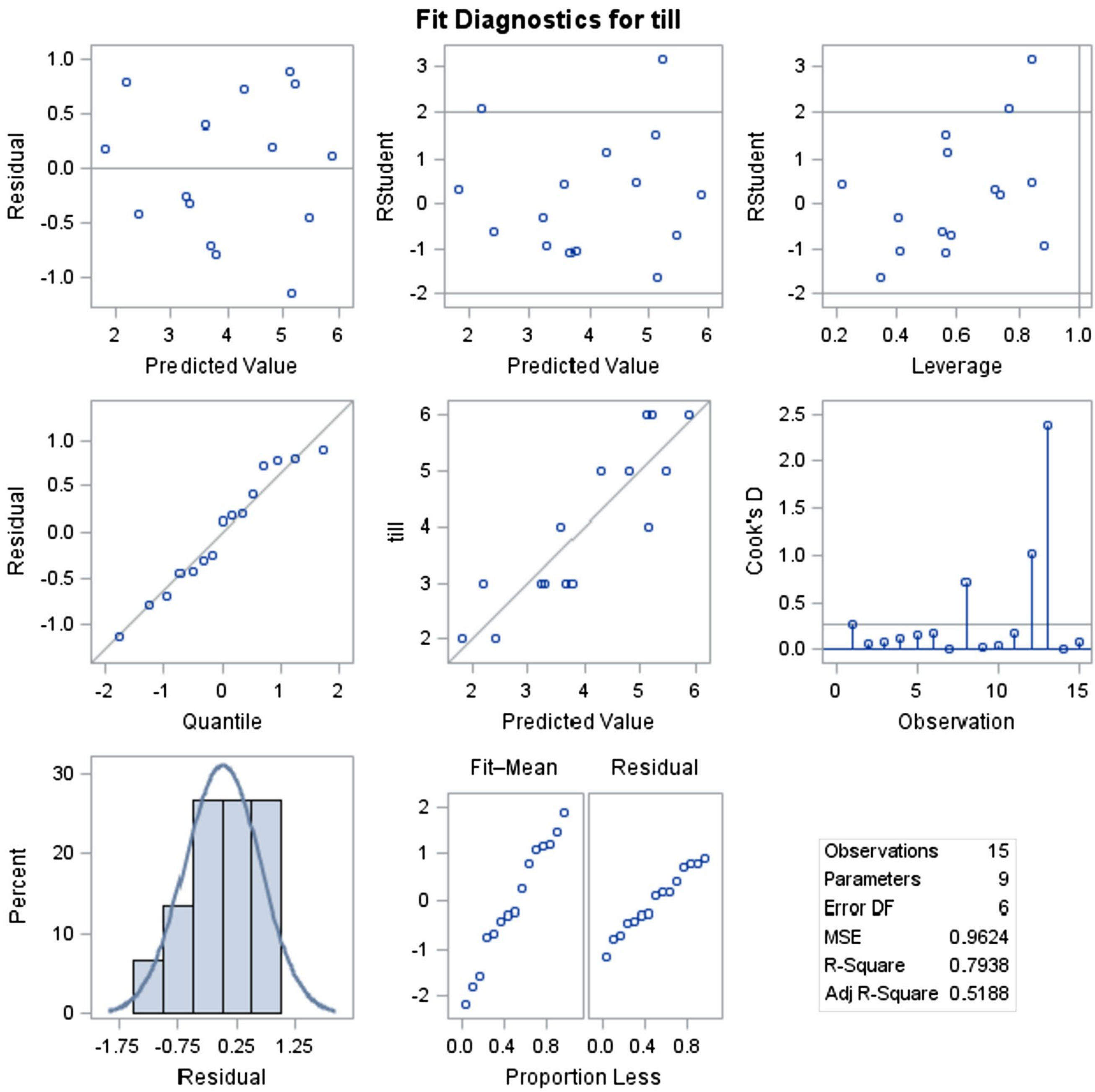


Fig. 5 The fit analyses of wheat tillers affected by the experimental parameters in the linear regression model

Wheat yield and yield components were also significantly correlated with chemical fertilization (Miransari and Mackenzie 2011; 2015), which indicates that optimum amounts of chemical fertilization increase wheat yield production in such regions. However, according to the above-mentioned details if such type of fertilization is combined with organic fertilization, the highest wheat yield may be achieved in such regions, which is of economic and environmental significance (Dimkpa et al. 2020).

SOC, TN, available K and P were highly and positively correlated, indicating that the increase of each parameter can contribute to the increase of the other parameters, and they can collectively enhance wheat yield production in such regions. However, interestingly, such parameters were highly and negatively correlated with soil salinity indicating their important role in controlling soil EC in such regions. Research has indicated that the availability of nutrients decreases is saline soil, however the use of organic matter has been indicated to be one of the effective methods to

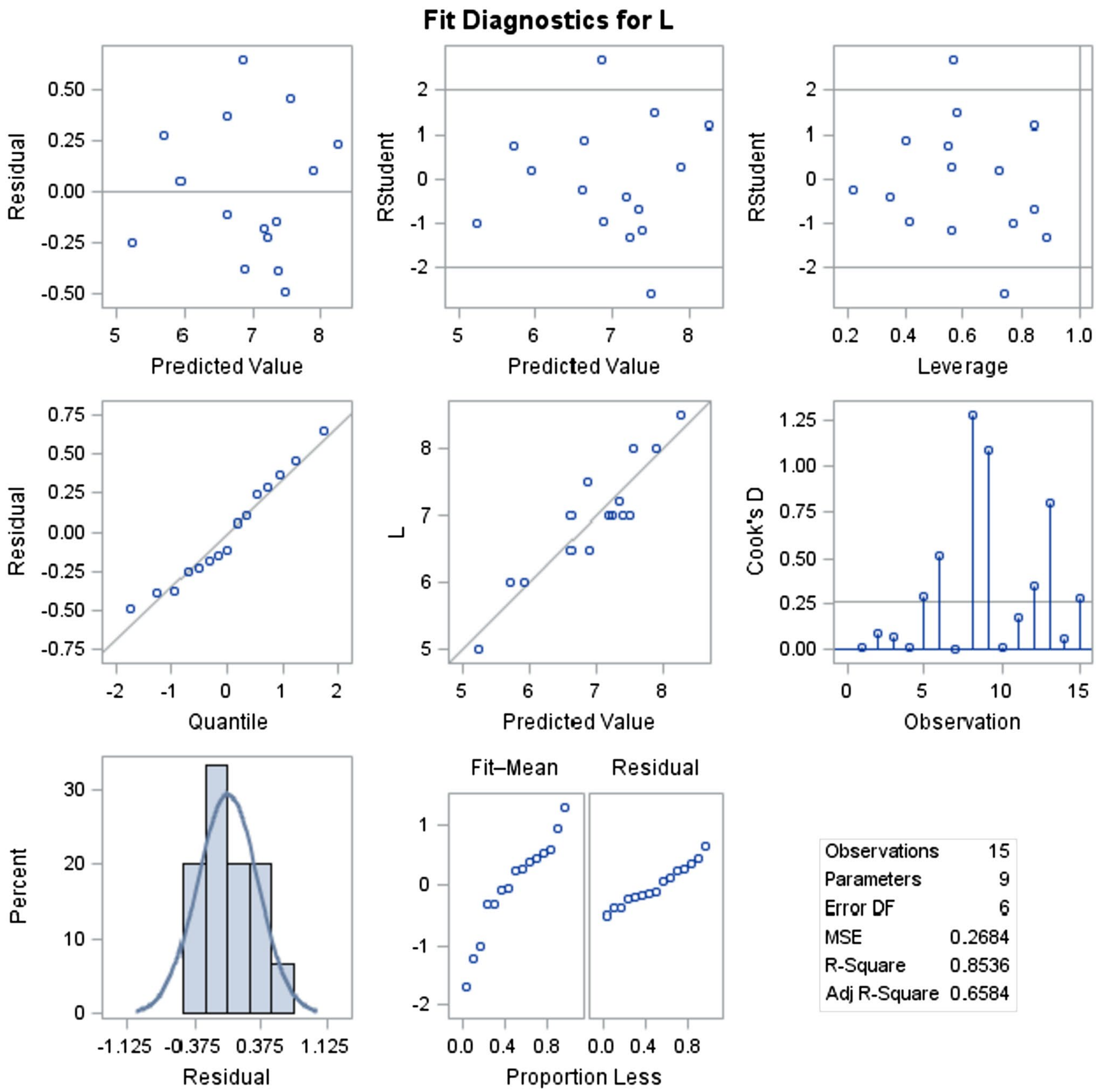


Fig. 6 The fit analyses of spike length affected by the experimental parameters in the linear regression model

alleviate salinity stress on soil physicochemical properties, plant growth and yield production (Duncan et al. 2018; Song et al. 2018).

The regression models proved the pertinent soil factors, that were selected and tested to determine the role of each factor in the production of wheat yield in the tested regions (Miransari and Mackenzie 2011; 2015). Plant height was the most affected parameter by the tested factors, followed by wheat biological and economic (grain) yields. The high R^2 values of the regression models indicate the response of wheat yield and yield components to the soil factors is linear, and due to the deficiency of the tested soil factors, the farmers must use proper practices and methods to increase wheat yield production in such regions. Oldfield et al. (2019) investigated the effects of soil organic matter on the production of wheat and maize yields, worldwide, and found that the maximum response of wheat and corn yields to SOC is at 2%. They also indicated that the increased levels of SOC decrease the use of chemical fertilization as well as wheat and corn yield gap. The three tested regions, in the present

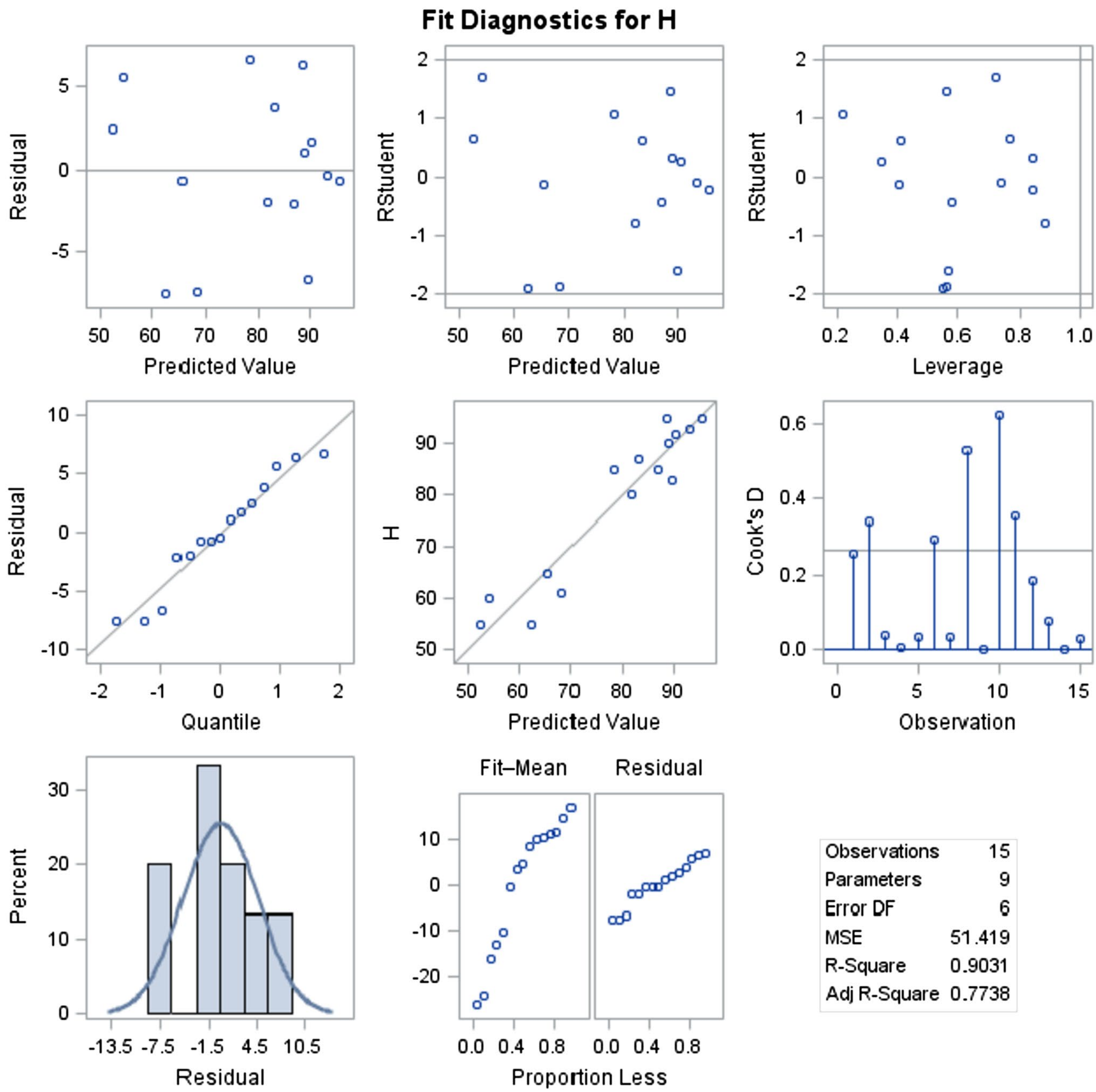


Fig. 7 The fit analyses of plant height affected by the experimental parameters in the linear regression model

research, followed almost a similar trend of climate indicating that the obtained results are comparable and can be used for such regions globally (van Bussel et al. 2015).

It must be noted that the processes of climate change and global warming affect soil factors such as SOC and soil available water (SAW) and subsequently soil productivity and yield production. It is accordingly an important research topic to find how climate change, especially in the arid- and semi-arid areas of the world may affect soil factors and hence plant growth (Azizi et al. 2024). With increasing temperature, the mineralization rate of SOC increases, which enhances the availability of soil nutrients for plant use, and decreases the presence of SOC affecting soil fertilization (Jat et al. 2018).

5 Conclusion

One important strategy, which can contribute to the increased production of wheat yield, is the identification of soil factors, which can significantly affect wheat yield

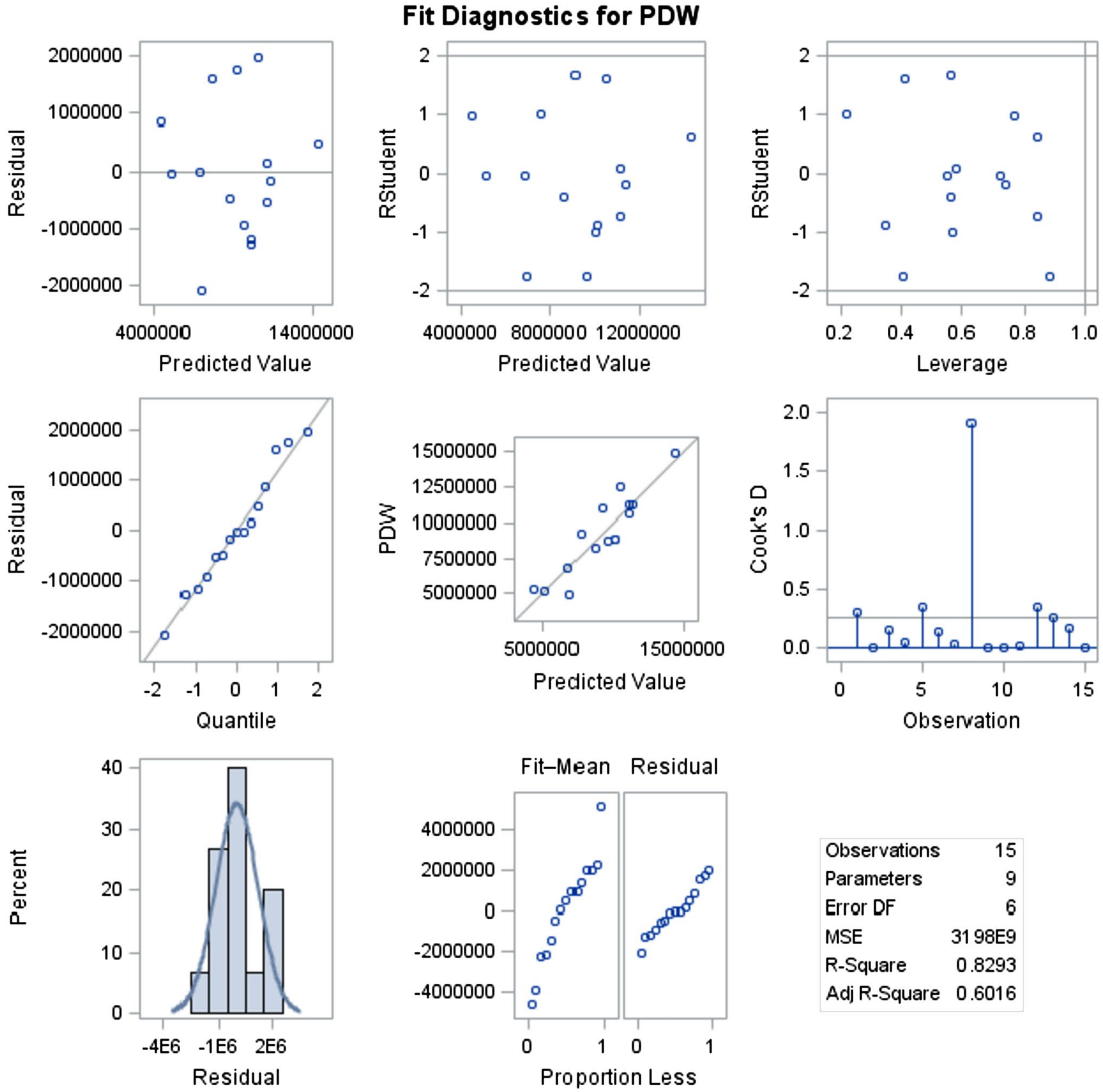


Fig. 8 The fit analyses of plant dry weight affected by the experimental parameters in the linear regression model

production in the arid-and semi-arid areas of the world. In the present research the actual and potential yields of wheat (yield gap) affected by different soil factors of texture, pH, salinity, SOC, TN, available P and K were investigated using linear regression models. Statistical analyses indicated that the three factors of SOC, TN and available K were the most important ones significantly affecting wheat yield and yield components in the tested regions. The regression models had the R^2 values ranging from 0.54 to 0.90, which indicates that 54 to 90% of variation of wheat yield and yield components in such regions is explained by the tested soil factors. Plant height (0.90) followed by biological (0.83), and economic (grain) yields (0.75) had the highest R^2 values, which indicates that the most effective soil factors have been selected and tested to determine wheat yield gap. If the fields in the arid- and semi-arid areas of the world are efficiently irrigated, according to our results, supplying such fields with organic matter, N and K can significantly decrease the yield gap and increase wheat yield to the desirable levels, which is of economic and environmental significance.

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Declarations

Conflict of interest The authors declare they do not have any conflict of interest.

Consent to participate Not applicable.

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