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Spring wheat response to nitrogen, tillage and cropping system under rainfed condition

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Abstract: The objective of this research work was to assess the existing summer fallow elimination by growing short duration leguminous crop (mungbean) and reduction in number of plows could be a good substitute in recent shift of rainfall pattern. The traditional tillage frequencies (exceeding 4–5 plow + 2 harrows) of the summer fallow land without the addition of commercial fertilizers to wheat are the century-old practices in the project area. The rainfall efficiency is very low and is certainly related to the low and marginal fertility status. The existing wheat–fallow–wheat (W–F–W) where field remains without crop for five–six months in summer was compared with the proposed wheat–mungbean–wheat (W–Mb–W) cropping system by eliminating the summer fallow. Four tillage systems, i.e. no tillage (NT), conventional tillage (CT), reduced tillage (RT), and maximum tillage (MT), were employed before wheat sowing. Wheat (Triticum aestivum L., cv. Tatara) was sown at the residual moisture of the monsoon rainfall and four levels of N (0, 25, 50, and 75 kg ha^{-1}) were added at the time of wheat sowing. Results show that the wetter year (second year) of the experiment had higher soil water (26.35%), grain yield (2,561 kg ha^{-1}), harvest index (43.5%), and water use efficiency (WUE) (6.1 kg ha^{-1} mm^{-1}). The existing W–F–W cropping system had more soil water (17%), grain yield (17%), harvest index (1%), WUE (9%), and grain N (23%) than W–Mb–W. CT system had more soil water (13%), grain yield (5%), WUE (2%), harvest index (3%), and grain N (5%) as compared with NT. CT also had more soil water contents (5%), grain yield (3%), WUE

ABOUT THE AUTHORS

The principal author and his family have a very long association as inhabitants as well as working farmers of the area and growing of cereal crops, exceptionally legume crops in the area. A numbers of adoptive trails on the farmer's field have already been conducted from the last 20–25 years involving bachelor's and master's students. With climatic change and in the improvement of livelihood of the community, cereal-based cropping system is not feasible any more. Instead, attention should be focused on the combined use both sources of fertilizers (organic and inorganic) and inclusion of legume crops for sustainable crop production in dryland is necessary. This minimum intervention is also socially acceptable for the farmers of the area.

PUBLIC INTEREST STATEMENT

Wheat–fallow–wheat or wheat–millet/sorghum–wheat is the dominant cereal-based cropping system in the project area. Since ages, application of farm yard manure is the sole source of plant nutrients. Wheat is sown on the residual moisture of the monsoon rainfall preferably in the last week of October, while millet/sorghum is grown during the current rainfall of the rainy season (July–August). With the recent introduction of farm machinery, reliance on the animal power has drastically reduced. Therefore, the reduction in numbers of livestock and farm yard manure declined the soil fertility in the study area. Two approaches to increase the soil fertility with introduction of legumes in summer gap instead of fallow and application of reasonable amount of inorganic fertilizers keeping in view the financial conditions of the farmers and expected yield based on the past experience were adopted.

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(10%),), and harvest index (3%) than MT. Nitrogen application had increased grain yield (33%), WUE (25%), harvest Index (3%), and grain N (7%) compared with the control (no N application). The present study does not suggest the replacement of summer fallow with mungbean crop as for as the grain yield and WUE is concerned. Apparently no negative impact of CT was recorded on grain yield and other parameters; however, to be on the safe side, RT with application of 75 kg N ha^{-1} is recommended for areas with similar rainfall pattern and soil fertility status.

Subjects: Agriculture and Food; Conservation-Environment Studies; Soil Sciences

Keywords: wheat; dryland; water use efficiency; grain N; grain yield; harvest index; cropping system; tillage and nitrogen

1. Introduction

Land fallowing is considered as a tool for mineralization of organic nitrogen (Jones, Skogley, Meints, & Martin, 1981). The concern that fallowing promotes soil and water losses has a greater potential for nitrate leaching and stagnancy in system has been reflected in literature from time to time. Intensive tillage is imposed for fine seedbed preparation, reduces weeds' intensity, improves soil moisture infiltration and crop yield (Temesgen, Rockstrom, Savenije, Hoogmoed, & Alemu, 2008), and has no negative impact on soil degradation and moisture preservation (Araya et al., 2012; Biazin & Sterk, 2013; Temesgen et al., 2008) in areas with meager precipitation. Conservation tillage having the pre-request of 30% of the crop residue on the soil surface is advocated on the ground of minimal soil disturbance (Bradford & Peterson, 2000; Gajri, Arora, & Prihar , 2002; Lahmar, 2010), improves soil quality (Fuentes et al., 2009) increases biodiversity, less costs (López, Blanco-Moure, Limón, & Gracia, 2012; Madejón, Moreno, Murillo, & Pelegrín, 2007), and also improves soil moisture and efficiency (Verch, Kächele, Höltl, Richter, & Fuchs, 2009). Reliance on the use of herbicides in case of conservation tillage has been warned earlier by Armstrong, Millar, Halpin, Reid, and Standley (2003). Biazin and Sterk (2013) are of the view that no tillage (NT) can result in higher run-off and lower infiltration that leads to lower yields. Contrary to the above statements, Vaclav, Vavera, Chpova, Kusa, and Ruzek (2013) reported that reduced tillage (RT) increased bulk density, reduced air filled pore spaces, retained higher water contents, and soil organic carbon (Javurek, Vach, & Strašil, 2007). Superiority of conservation tillage over conventional tillage (CT) can be achieved in long-term experiments (Erenstein, 2003; Giller, Witter, Corbeels, & Tittonell, 2009). CT provides greater agronomic and economic benefits compared with minimum tillage and zero tillage (Sime, Aune, & Mohammed, 2015).

Arnon (1992) proposed that in rainfed farming, improving certain simple cultural practices that do not require expensive inputs (more careful tillage, better stands of plants, timely sowing, and weeding and moisture conservation) could all contribute to improved yields. Furthermore, crop rotation, appropriate tillage methods, the use of improved and adapted varieties in conjunction with fertilizer application, and crop protection have proved to effect dramatic increases in yields, even in the areas with problematic moisture regime. The present three-year project was initiated with minimum intervention keeping in view the socioeconomic conditions of farmers with the aim to ascertain the influence of (i) summer fallow elimination with short duration rainy season and well-adopted crops like mungbean, (ii) reduction in the tillage intensity, and (iii) the application of commercial nitrogen fertilizer on rainfed wheat yield. It was assumed that the increase in summer rainfall distribution witnessed within the last five–six years in the area may sustain (a) growth of both season crops and (b) will improve fertility status due to inclusion of the summer legume (Mungbean) with RT frequency and nitrogen fertilization or the adoption of only summer crops and fallowing of winter. The proposed study may help the farmers switch over to summer cropping (winter fallow–summer cropping–winter fallow) instead of the existing one.

2. Materials and methods

2.1. Experimental site

Field trials were conducted for three consecutive years (2005–2008) at the district Karak Khyber Pakhtunkhwa Province of Pakistan. Its coordinates are 33°7′12″ N and 71°5′41″ E in DMS at an altitude of 469 m. The cropping system in the area is predominantly dependent upon the amount of rainfall received during the monsoon season (July–August). In October–November, wheat is sown on the residual moisture of the monsoon rainfall (which occurred during mid-July–late-August) and virtually, there is no or negligible rainfall from October to December. To conserve the moisture of the monsoon season, farmers of the area plow the field with CT after every shower of rain during the two months of monsoon with the aim to allow more water to infiltrate. The traditional tillage frequencies (exceeding four–five plow + 2 harrows) of the summer fallow without the addition of commercial fertilizers to the coming main crop like wheat are century-old practices in the project area. The existing wheat–fallow–wheat (W–F–W) where field remains without crop for five–six months in summer is also based on old tradition, in spite of the fact that most of the rainfall occurs during the fallow period (June–September). The proposed wheat–mungbean–wheat (W–MB–W) cropping system (elimination of summer fallow) along with four tillage systems, i.e. NT, CT, RT, and maximum tillage (MT), was employed before wheat sowing. Rainfall data for the last 30 years reveal that the area received an average rainfall of 410 mm per annum having 132 mm in the wheat-growing season (33%). For recording rainfall, a rain gauge was installed at the field of experiment. Soil sampling analysis shows that the experimental site is coarse loamy, mixed, typical Udorthents having a pH of 7.9 and EC_e 0.22 ds m^{-1}. The soil initially had 0.74% organic matter.

2.2. Experimental details

Soil sample for nitrogen and soil moisture determination was collected before and after termination of each of the season of experiments for three consecutive years. Two cropping systems, i.e. W–F–W and W–Mb–W, with four tillage systems (NT, CT, RT, and MT) were applied before wheat sowing. In case of tillage system, no plowing, two times plowing, four times plowing, and eight times plowing by the cultivator are referred as NT, RT, CT, and MT, respectively. Tillage continued till the sowing of wheat in plots reserved for W–F–W system after wheat harvest to the next wheat-sowing season as a farmer practice to open the soil for moisture conservation of the current rainfall, if any. Wheat variety Tatara was sown at the seed rate of 75 kg ha^{-1}. Row-to-row distance was 30 cm in sub plot size of 17 × 6 m, replicated thrice. Four levels of N (0, 0.25, 0.50, and 0.75 kg ha^{-1}) were applied to wheat crop at the time of final seedbed preparation each year. Weeds in case of NT were controlled by application of post-emergence herbicides. Recommended dose of phosphorus (60 kg P_2O_5) for rainfed wheat was applied at the time of final seedbed preparation and wheat seeds were sown on residual moisture. In the case of NT, sowing was done with the help of a dibbler. The combination of cropping system and tillage was allotted to the main plot, while N levels were allotted to the subplot. The experiment was laid out in randomized complete block design with split plot arrangements.

2.3. Soil and plant analysis

Before sowing both crops (wheat and mungbean), each sub plot was cored to 100 cm and sectioned by depths of 0–15, 15–30, 30–45, 45–60, and 60–100 cm. Stainless steel (50 × 50 mm) was used for collection of samples. The 0–15-cm samples were air dried, finely ground, passed through a <0.2-mm sieve, and analyzed for total N. Soil total N was measured using Kjeldahl method of Bremner and Mulvaney (1982). For mechanical analysis of the soil, the hydrometer method of Bouycous was used. The percentage of sand, silt, and clay was read on a textural triangle to determine the soil texture and percentage of silt, sand, and clay in the experimental site. Soil pH was calculated using Thomas method in which a suspension was made with soil:water ratio (1:2.5) in which 10 g of air-dried soil sample was shaken with 25 ml of distilled water for 30 min and after calibrating the pH meter, pH was recorded with pH meter. Electrical conductivity was measured in the soil water suspension using conductivity meter by the method described by Rhoades. Soil moisture contents were determined gravimetrically at the beginning of each season and at the harvest of both crops. Water use efficiency (WUE) was calculated by the method described by Lopez et al..

2.4. Statistical analysis

Data recorded were analyzed according to the randomized complete block design with split plot arrangement. *F*-test was used for the separation of mean significance for treatment effect and LSD test was applied for mean comparison at 5% level of probability (Gomez & Gomez, 1983).

3. Result and discussion

3.1. Year effect

October and November are considered the best times for wheat sowing in the area and rainfall during these months is very exceptional. Moisture preservation of the summer monsoon where the field is fallow during this period is therefore a prerequisite to ensure the timely sowing and subsequent yield of winter crops like wheat. The amount of rainfall received during the year 2006–07 (second year of the experiment) was 43% higher than the first year and 59% more than third year, especially from July to September which is the monsoon season for rainfall in the project area (Figure 1). This increase in rainfall had significantly increased the moisture availability at the time of wheat sowing (Table 1) and resultantly had significantly improved grain yield (2,561 kg ha^{-1}), harvest index (HI) (43.5%), WUE (6.08 kg ha^{-1} mm^{-1}), and grain nitrogen (GN) (2.13%) as compared with the other years of the experiments. Similar relationships between water availability and yield of some crops have been reported by Norwood. Nielson et al. have observed a linear relationship between wheat yields and increase in availability of soil water at wheat planting time.

3.2. Cropping system effect

Mean values of Table 2 show that fields with traditional system of W–F–W cropping system had accumulated significantly more moisture contents (24.52%), produced higher grain yield (1,957 kg ha^{-1}), and higher WUE (5.72 kg ha^{-1} mm^{-1}) than with W–Mb–W cropping system. The lower moisture contents of W–MB–W indicated that the mungbean crop (elimination of summer fallow) has depleted the moisture as expected and is in agreement with those of Nielsen who recorded a similar trend with the elimination of summer fallow. Vigil and Nielson reported that water used by legumes within three months of its growth was greater than subsequent wheat whole crop duration in their study. Reduction in wheat yield by inclusion of summer legumes than fallow system because of low soil moisture at wheat sowing has also been reported by Zentner, Campbell, Biederbeck, and Selles (1996). The lower availability of moisture at the time of sowing of wheat in W–Mb–W cropping system seems to be responsible for the significantly lower grain yield (1,626 kg ha^{-1}), lower WUE (5.18 kg ha^{-1} mm^{-1}), and lower GN concentration of 1.71%. Our findings are supported by Vigil and Neilson who observed that grain yield of wheat following legumes was lower than the summer fallow system. Replacing the fallow period with continuous cropping reduces crop water productivity of semi-arid wheat (Aiken, Brien, Olson, & Murray, 2012) and furthermore, crop reduced biomass and grain yield were the combined effect of continuous cropping. From the current finding, it seems that

Figure 1. Rainfall pattern/ distribution during the three years (2005–2008).

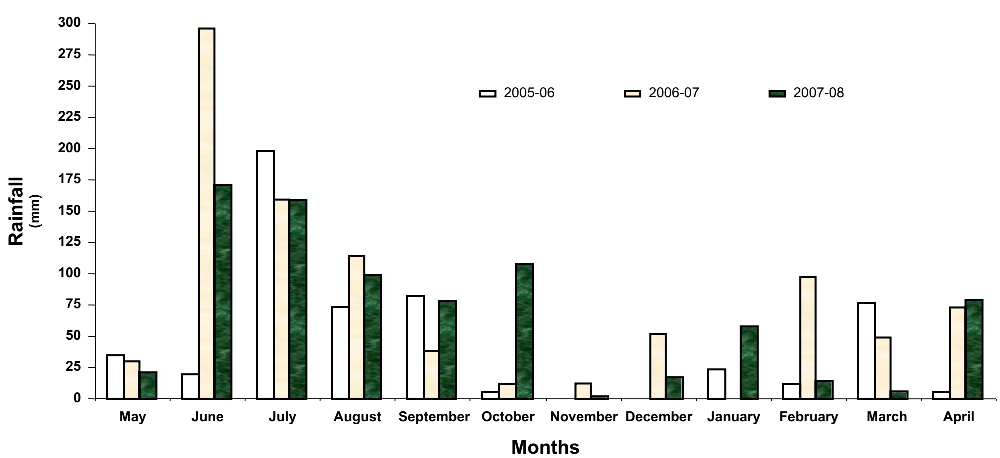


Table 1. Soil water contents, grain yield harvest index, water use efficiency, and grain nitrogen of dryland wheat as affected during the three years (2005–2008)

Parameters	Year-1	Year-2	Year-3
Water contents of soil (%) by weight	19.71^{c}	26.35^{a}	21.32^{b}
Grain yield (kg ha^{-1})	1,481^{c}	2,561^{a}	1,804^{b}
Harvest index (%)	40.1^{b}	43.5^{a}	41.01^{b}
Water use efficiency (kg ha^{-1} mm^{-1})	5.85^{b}	6.08^{a}	3.53^{c}
Grain nitrogen concentration	1.91	2.13	1.88

Notes: Year-1 = 2005–2006, Year-2 = 2006–2007, and Year-3 = 2007–2008.

Means within the row with different superscript letters are significantly different at 5% probability level using LSD.

Table 2. Soil water contents, grain yield harvest index, water use efficiency, and grain nitrogen of dryland wheat as affected by cropping system

Parameters	W–F–M	W–Mb–M
Water contents of soil (%) by weight	24.52^{a}	20.42^{b}
Grain yield (kg ha^{-1})	1,957^{a}	1,626^{b}
Harvest index (%)	39.89	39.49
Water use efficiency (kg ha^{-1} mm^{-1})	5.72^{a}	5.18^{b}
Grain nitrogen concentration	2.23^{a}	1.71^{b}

Notes: W–F–M = Wheat–Fallow–Wheat and W–Mb–M = Wheat–Mungbean–Wheat.

Means within the row with different superscript letters are significantly different at 5% probability level using LSD.

adopting W–Mb–W (summer fallow eliminations) cannot be recommended as it drastically reduced residual moisture for subsequent wheat production.

3.3. Tillage system effect

Table 3 reveals that tillage had a significant effect on moisture contents, grain yield, HI, and GN. Plots having NT system had significantly lower moisture contents (18.65%), grain yield (1,693 kg ha^{-1}), HI (39.55%), and GN (1.86%) than RT and CT; however, it was par with MT for grain yield and HI. The lowest moisture contents in NT are probably due to less infiltration or because of continuity of soil capillary column in NT system where faster loss of water is expected. In the case of MT, the greater loss of moisture is probably due to frequent plowing which exposed the soil moisture to evaporation. Significant reduction in infiltration rate in RT and NT has been reported by Matula (2003). Rieger, Richner, Streit, Frossard, and Liedgens (2008) reported that grain yield was 3% lower under NT as compared with CT and MT in their study. Our result regarding the highest grain N contents in CT compared with NT are in agreement with those of Halvorson, Wienhold, and Black (2001). Tillage indirectly affects grain protein via increase in soil moisture (Trethowan, Mahmood, Ali, Oldach, & Garcia, 2012); however, Gursoy, Sessiz, and Malhi (2010) found no relationship between grain protein and tillage. We could not detect significant variation in GN among the other three tillage systems

Table 3. Soil water contents, grain yield, harvest index, water use efficiency, and grain nitrogen of dryland wheat as affected by tillage system

Tillage system	Moisture	GY	WUE	HI	GN
No tillage (NT)	18.65^{c}	1,693^{b}	7.40^{a}	39.55^{b}	1.86^{b}
Reduced tillage (RT)	21.92^{a}	1,797^{a}	7.91^{a}	40.87^{a}	2.01^{a}
Conventional tillage (CT)	21.44^{a}	1,778^{a}	7.59^{a}	40.88^{a}	1.96^{a}
Maximum tillage (MT)	20.24^{b}	1,716^{b}	6.79^{a}	39.75^{b}	1.99^{a}

Notes: Soil moisture (%) by weight, GY = Grain yield kg ha^{-1}, WUE = (kg ha^{-1} mm^{-1}), HI = Harvest Index (%), and GN = grain nitrogen (%).

Means within the column with different superscript letters are significantly different at 5% probability level using LSD.

Table 4. Soil water contents, grain yield, water use efficiency, harvest index, and grain nitrogen of dryland wheat as affected by nitrogen levels.

Nitrogen (kg ha^{-1})	Moisture	GY	WUE	HI	GN
00	20.81^{a}	1,410^{d}	5.82^{d}	39.38^{a}	1.88^{a}
25	20.81^{a}	1,659^{c}	6.90^{c}	38.77^{a}	1.90^{a}
50	20.81^{a}	1,805^{b}	7.02^{b}	40.43^{a}	2.01^{a}
75	20.81^{a}	2,110^{a}	7.77^{a}	40.48^{a}	2.02^{a}

Notes: Moisture (%), GY = Grain yield kg ha^{-1}, WUE = (kg ha^{-1} mm^{-1}), HI = Harvest Index (%), and GN = grain nitrogen (%). Means within the column with different superscript letters are significantly different at 5% probability level using LSD.

used (RT, CT, and MT). Overall, RT and CT performed better than NT and MT by maintaining higher moisture contents, grain yield, HI, and GN.

3.4. Nitrogen effect

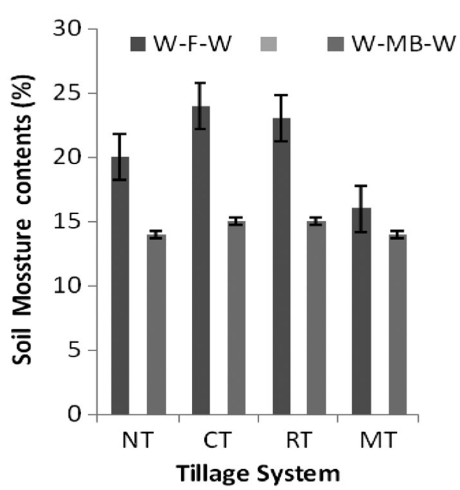
With increase in N levels, grain yield and WUE significantly increased (Table 4). Plots without N application had the lowest grain yield and WUE, while those plots supplied with 75 kg ha^{-1} had highest grain yield (2,110 kg ha^{-1}) and WUE of 7.77 kg ha^{-1} mm^{-1}). Increase in grain yield and WUE with increase in N fertilizer application was higher than no N application in our study and is in line with those of Power. The values we obtained for WUE are in range to those of Onken et al. for rainfed wheat supplied with 90 kg ha^{-1}(7.95–9.10 kg ha^{-1} mm^{-1}). Grain N, although, increased with increase in N level, but this difference was not significant in our study.

3.5. Interactive effect

Interaction for the cropping system × tillage given in Figure 2 shows significant variation in moisture availability at the time of wheat sowing. In the cropping system of W–F–W, there was more accumulation of moisture. CT and RT had accumulated more moisture as compared with that of NT and MT under W–F–W system; however, no changes in soil moisture with tillage system in W–Mb–W were noticed. This no change due to tillage system could be due to the utilization of moisture by mungbean crop during its three-month growth period and furthermore, the soil was exposed to tillage operation for shorter periods of time as compared with W–F–W cropping system where these tillage practices continued for longer periods during fallowing. Variation within tillage operations was not statistically significant. It further reveals that mungbean crop (W–Mb–W) has depleted the moisture which otherwise could have been available for wheat at sowing. The relationship of moisture availability with grain yield given in Figure 3 shows that during the three years of the experiments, grain yield depended upon the availability of moisture at the time of sowing of wheat as those plots having higher moisture at planting produced more grain yield. Figure 4 reveals that although the second

Figure 2. Percent moisture availability at wheat sowing time, as affected by cropping system and tillage (2005–2008).

Note: Vertical bars represent SE of means of three replicates.



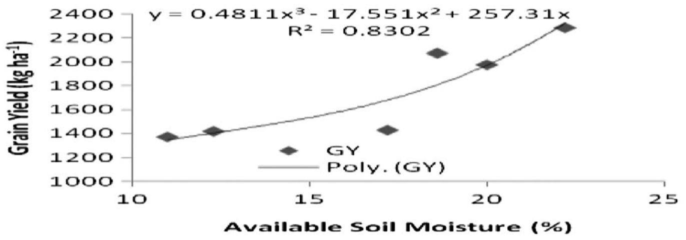


Figure 3. Grain yield of wheat as affected by moisture availability at the time of sowing (2005–2008).

Note: Vertical bars represent SE of means of three replicates.

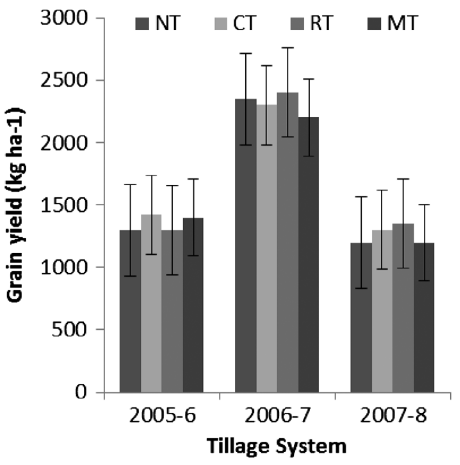


Figure 4. Grain yield as affected by tillage system and years 2005–2008 wheat-growing season.

Note: Vertical bars represent SE of means, values of the means of three replicates.

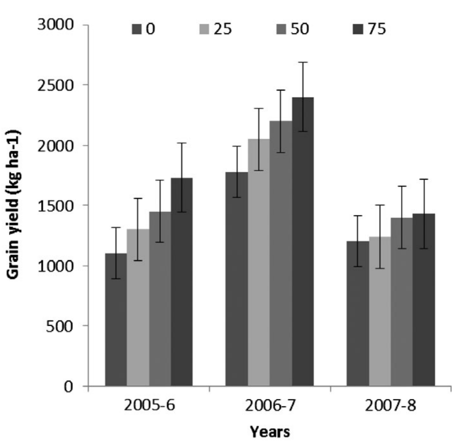


Figure 5. Grain yield as affected by N levels during the period 2005–2008 wheat-growing season.

Note: Vertical bars represent SE of means, values of the means of three replicates.

wetter year having more rainfall produced more grain yield, the trend of tillage system was similar irrespective of the year of the experiment and moisture availability and has subsided the role of the tillage. The response of N application was also related with amount of rainfall as higher grain yield was observed with amount of higher rainfall coupled with the amount of fertilizer N application to the wheat crop (Figure 5). It implies that farmers of the dryland should devise a flexible cropping system and the amount of N application as per the availability of the water in pre-sowing season.

4. Conclusions

Variation in the amount and distribution of rainfall especially in arid and semi-arid areas is not surprising; however, flexible cropping systems having pre-crop moisture conservation practices are required. Introduction of short duration (rainy season) crops preferably leguminous (mungbean) as summer fallow elimination seems to be beneficial on a long-term basis due to N fixation and crop residue leftover; however, it will reduce subsequent wheat yield mainly because of moisture depletion on short-term basis. The existing cropping system of W–F–W preferably with RT system having 75 N kg ha^{-1} applications to the wheat crop is recommended.

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Competing interests
The authors declare no competing interest.

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[§] Amanullah Jan designed and supervised the research project, Amanullah drafted and revised the manuscript, and Nazim Hussain carried out the lab and field studies, and performed the statistical analysis of the data. All authors read and approved the final manuscript.

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