THE CROP JOURNAL 3 (2015) 118–124

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Bed planting of wheat (*Triticum aestivum* L.) improves nitrogen use efficiency and grain yield compared to flat planting

Abdul Majeed, Atif Muhmood, Abid Niaz, Shahid Javid, Zahid Ashfaq Ahmad, Syed Shahid Hussain Shah, Asrar Hussain Shah*

Soil Chemistry Section, Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute, Faisalabad, Pakistan

ARTICLE INFO

Article history:
Received 20 June 2014
Received in revised form
6 January 2015
Accepted 16 February 2015
Available online 21 February 2015

Keywords:
Bed and flat planting
N uptake
N use efficiency
Grain yield

ABSTRACT

Conventional flat planting is commonly used for growing wheat in Pakistan and the crop is irrigated by flood irrigation, but it leads to ineffective use of applied nitrogen owing to poor aeration and leaching and volatilization losses. The practice also results in greater crop lodging, lower water use efficiency, and crusting of the soil surface. In contrast, bed planting of wheat not only saves water but improves fertilizer use efficiency and grain yield. Three years of pooled data from the present study showed that wheat planting on beds and nitrogen application at 120 kg ha^{-1} produced 15.06% higher grain yield than flat planting at the same nitrogen rate. Similarly, 25.04%, 15.02%, 14.59%, and 29.83% higher nitrogen uptake, nitrogen use, and agronomic and recovery efficiencies, respectively, were recorded for bed compared to flat planting. Wheat planting on beds with a nitrogen application of 80 kg ha^{-1} gave a yield similar to that of flat planting with 120 kg ha^{-1} nitrogen. However, the economic return was 29% higher in bed planting as compared to flat planting, when nitrogen was applied at 120 kg ha^{-1}.

1. Introduction

Wheat is not only the most important cereal crop in the world but also the major staple food for the people of Pakistan [1]. It contributes 10.1% to the value added in agriculture and 2.2% to the gross domestic product, and was cultivated over an area of 8,693,000 ha during 2012–2013 [2]. Wheat as a Rabi (winter) crop is usually planted either by drilling the seed in rows while maintaining a row-to-row distance of 22.5 or by broadcasting the seed on a leveled soil surface and then incorporating it by shallow tillage following planking and flood irrigation, especially in irrigated areas. Despite its high yield potential, yield per hectare is very low in Pakistan compared to that in other wheat producing countries [3]. Better irrigation and soil management technologies are needed to improve water and fertilizer use efficiency. These resource conservation technologies include mainly bed planting of wheat, sowing of wheat using zero tillage, and laser land leveling of fields. The system of wheat bed planting for irrigated conditions that has been widely adopted by farmers in northwest Mexico offers an innovative option for expanding wheat production practices in other countries.

* *Corresponding author.*
E-mail address: majeed_agrarian@yahoo.com (A. Majeed).
Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.

http://dx.doi.org/10.1016/j.cj.2015.01.003

The bed planting system facilitates mechanical cultivation as an alternative method of weed control during the crop growing season. It also provides an opportunity for hand weeding, an economical option because of the easy field entry resulting from crop row orientation on the beds, and irrigation water management is more efficient, with less labor required with the use of furrows than with conventional flood irrigation [4,5]. Under the flat planting method, crop production and fertilizer use efficiency have stagnated or decreased. In addition to these problems, the nitrogen use efficiency (NUE) for wheat cultivation is only about 30%, but with best management practices it can be raised to higher levels [6,7]. Optimal nitrogen (N) management is essential for maximum NUE, crop yield and lowest environmental pollution [8]. Applying less N may result in lower grain yields and reduced grain quality. However, higher N application can result in reducing NUE and increasing fertilizer losses. Efficient use of applied N fertilizer increases crop yield and reduces the cost of crop production. N use and recovery efficiencies depend on soil properties; method, source and timing of fertilizer application; and crop planting methods [9,10]. Improving NUE is one approach to producing higher grain yield with low inputs of N [11,12]. Wheat flat planting with flood irrigation leads to inferior water use efficiency and lower crop yield. This practice also results in greater crop lodging and enhanced frequency of crop diseases [13]. Wheat planted on beds and furrow irrigation showed higher yield and water use efficiency than flat-planted wheat [14]. Wheat flat planting with an N application of 120 kg ha^{-1} is a common practice in irrigated areas of Pakistan. The objectives of this study were to compare NUE and grain yield of wheat under bed and flat planting methods with different doses of N on a sandy clay loam soil.

2. Materials and methods

2.1. Site description and method of planting

A field experiment was conducted at the farm of the Soil Chemistry Section, Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute Faisalabad, Pakistan for three continuous years (2010–2011, 2011–2012, and 2012–2013). The climate of the experimental area is semiarid with hot dry summer and cold winter seasons. During the cropping seasons the rainfall pattern was erratic. Rice–wheat was the cropping system and flood and furrow irrigations were practiced in flat and bed planting methods, respectively. Raised beds (15 cm high and 90 cm wide with 60-cm tops and 30-cm furrows) were made with a bed planting machine following the conventional land preparation. Wheat seeds were sown in rows in both bed and conventional (flat planting) methods. For beds, seeds were sown at four rows per bed (Fig. 1A and B). In this way the number of rows remained the same as with flat planting by Rabi drill. The first row was sown at 7.5 cm from either side of the bed and the second row was sown 12.5 cm from the first, with 20 cm in the center of the bed remaining without a crop. For conventional planting, the row-to row-distance was 22.5 cm.

2.2. Description of treatments and fertilizer application

The treatments used in the field experiment included T1, flat planting (0 kg N ha^{-1}); T2, bed planting (0 kg N ha^{-1}); T3, bed planting (60 kg N ha^{-1}); T4, bed planting (80 kg N ha^{-1}); T5, bed planting (100 kg N ha^{-1}); T6, bed planting (120 N kg ha^{-1}); and T7, flat planting (120 N kg ha^{-1}). All treatments were repeated three times. Recommended applications of N, phosphorus (P), and potassium (K) were applied at 120, 90, and 60 kg ha^{-1} in the forms of urea, single superphosphate, and sulfate of potash, respectively. Full doses of N, P, and K were applied at final land preparation before wheat planting.

Fig. 1 – Wheat crop on beds. (A) at early stage; (B) at harvesting stage.

Table 1 – Soil physicochemical properties of the experimental field.

Characteristic	Unit	Value
Sand	%	53.64
Silt	%	21.08
Clay	%	25.28
Textural class	–	Sandy clay loam
Saturation percentage	%	34.7
pH_s	–	8.14
EC_e	$dS\ m^{-1}$	1.65
Organic matter	%	0.66
Total nitrogen	%	0.025
Available phosphorus	$mg\ kg^{-1}$	8.86
Extractable potassium	$mg\ kg^{-1}$	208

2.3. Plant and soil analysis

Before wheat sowing, a composite soil sample was collected from the field and analyzed for physicochemical properties. The soil was low in organic matter, marginal in available P, but sufficient in K (Table 1). The pH of a soil paste and electrical conductivity of a soil extract was measured following [15], P was measured with spectrophotometer following sodium bicarbonate extraction [16] and the textural class was determined by the hydrometer method [17]. Soil organic matter content was estimated following Ryan et al. [18]. For K, soil extraction with ammonium acetate (1 mol L^{-1}, pH 7.0) was performed and K was determined with a Flame photometer (PFP-7 Jenway, Bibby Scientific Ltd. UK) [16]. At harvest, data for agronomic traits including number of spikes per square meter, number of grains per spike, 1000-grain weight (g), and grain yield (t ha^{-1}) were recorded. An area of 9 m^2 was harvested randomly from the center of each plot. The harvest of each plot was collected, labeled, sun-dried, and threshed individually. Grain and straw samples were taken and dried in an oven at 70 °C. For N determination, dried ground material (0.5 g) was digested with sulfuric acid using a digestion mixture ($CuSO_4$, Se, and $FeSO_4$), distilled, and titrated against 0.05 mol L^{-1} H_2SO_4 [19].

2.4. Nitrogen use efficiency and its components

N uptake, NUE, N agronomic efficiency (NAE), and N recovery efficiency (NRE) were calculated following [20–22].

$$\text{N uptake} = \frac{\text{N contents (\%) in plant parts (dry matter)} \times \text{yield}\left(\text{kg ha}^{-1}\right)}{100} \quad (1)$$

$$\text{NUE} = \frac{\text{Grain yield}\left(\text{kg ha}^{-1}\right)}{\text{N dose applied}\left(\text{kg ha}^{-1}\right)} \quad (2)$$

$$\text{NAE} = \frac{\left[\text{grain yield}\left(\text{kg ha}^{-1}\right)\text{ in fertilized plot– grain yield}\left(\text{kg ha}^{-1}\right)\text{ in control plot}\right]}{\text{N dose applied}\left(\text{kg ha}^{-1}\right)} \quad (3)$$

$$\text{NRE} = \frac{\left[\text{total N uptake}\left(\text{kg ha}^{-1}\right)\text{ in fertilized plot–total N uptake}\left(\text{kg ha}^{-1}\right)\text{ in control plot}\right]}{\text{N dose applied}\left(\text{kg ha}^{-1}\right)} \quad (4)$$

2.5. Statistical and cost–benefit analysis

Each year's repeats of each treatment during the three years of the experiment were pooled, and statistical analysis was performed using Statistics 8.1 (http://statistix.software.informer.com/). Least significant differences (LSDs) were used for comparing treatment means [23]. On the basis of variable and market prices, a cost-–benefit analysis was performed by dividing gross income by total expenditure (Table 4) to estimate the economic feasibility of bed planting and N application rate for increasing wheat production and net economic return, as described by CIMMYT [24].

3. Results

3.1. Wheat grain yield and its attributes

The planting of wheat in a flat planting pattern with the application of 120 kg N ha^{-1} is a common practice in Punjab province, Pakistan. This practice was compared with bed planting using N fertilizer application rates from zero to 120 kg ha^{-1} with the aim of determining whether or not the conventional or any other rate of nitrogen fertilizer on bed plantings leads to an increased yield. The three years of pooled data showed that increasing N application to

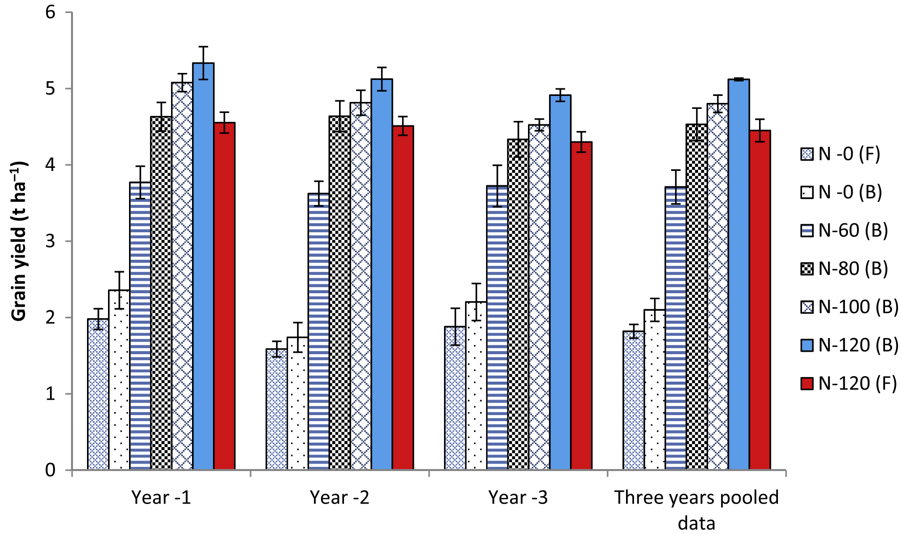

Fig. 2 – Effect of planting method and nitrogen levels on wheat grain yield. N-0 (F) = T_1, (0 kg N ha^{-1} flat planting), N-0 (B) = T_2, (0 kg N ha^{-1} bed planting), N-60 (B) = T_3, (60 kg N ha^{-1} bed planting), N-80 (B) = T_4, (80 kg N ha^{-1} bed planting), N-100 (B) = T_5, (100 kg N ha^{-1} bed planting), N-120 (B) = T_6, (120 kg N ha^{-1} bed planting), N-120 (F) = T_7, (120 kg N ha^{-1} flat planting).

120 kg ha^{-1} in bed planting increased wheat yield up to 5.12 t ha^{-1}, statistically higher than the yield (4.45 t ha^{-1}) in flat planting at the same N rate (Fig. 2). Bed planting along with N applications of 80 and 100 kg ha^{-1} were non-significant with each other, but 120 kg N ha^{-1} application on beds resulted in a significantly greater yield than 120 kg N ha^{-1} with flat planting. The results showed (Fig. 1) that planting wheat on beds with the application of 80 kg N ha^{-1} gave statistically identical yield (4.63, 4.64, and 4.33 t ha^{-1}) to that of 120 kg N ha^{-1} application in flat planting (4.55, 4.51, and 4.30 t ha^{-1}) in seasons 1, 2, and 3, respectively. Pooled data of number of grains per spike and 1000-grain weight were significantly higher in bed planting with the application of 120 kg N ha^{-1} than flat planting at the same N rate. Wheat planting on beds with the application of 120 kg N ha^{-1} produced 15.06%, 13.04%, 6.10%, and 7.50% higher grain yield, number of grains per spike, 1000-grain weight, and harvest index than conventional flat planting at the same N rate (Fig. 3).

3.2. N uptake in wheat grain and straw

On average, the three years of pooled data showed that maximum N uptakes (110, 105, and 94 kg ha^{-1}) by grain were observed under bed planting (where N was applied at 120, 100, and 80 kg ha^{-1}), whereas under flat planting (where N was applied at the rate of 120 kg ha^{-1}), 88 kg ha^{-1} N uptake by grain was observed. This result showed that higher N uptake

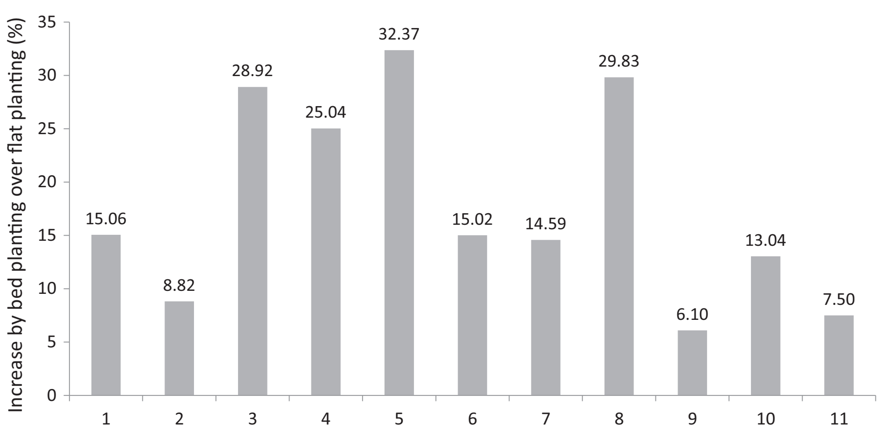

Fig. 3 – Comparative increase in different parameters under bed relative to flat planting with application of 120 kg N ha^{-1}. (1) Grain yield (t ha^{-1}); (2) N in grain (%); (3) N in straw (%); (4) N uptake in grain (kg ha^{-1}); (5) N uptake in straw (kg ha^{-1}); (6) N use efficiency (kg kg^{-1}); (7) N agronomic efficiency (kg kg^{-1}); (8) N recovery efficiency (kg kg^{-1}); (9) 1000-grain weight (g); (10) number of grains/spike; (11) harvest index (%).

Table 2 – Effect of planting method and nitrogen dose on nitrogen uptake in grain and straw and on nitrogen agronomic efficiency.

Treatment (N kg ha^{-1})	N uptake in grain (kg ha^{-1})				N uptake in straw (kg ha^{-1})				N agronomic efficiency (kg kg^{-1})			
	Year 1	Year 2	Year 3	Pooled	Year 1	Year 2	Year 3	Pooled	Year 1	Year 2	Year 3	Pooled
N-0 (F)	19 d	16 d	22 e	19 d	10 d	6 e	8 d	8 f	–	–	–	–
N-0 (B)	25 d	19 d	26 e	23 d	9 d	6 e	10 d	8 f	–	–	–	–
N-60 (B)	67 c	67 c	73 d	69 c	24 c	22 d	26 c	24 e	24 a	31 ab	25 a	27 ab
N-80 (B)	94 b	95 b	93 bc	94 b	35 b	31 c	34 b	33 d	28 a	36 a	27 a	30 a
N-100 (B)	110 a	101 ab	102 ab	105 a	51 a	38 ab	46 a	45 b	27 a	31 abc	23 a	27 ab
N-120 (B)	115 a	107 a	110 a	110 a	55 a	41 a	51 a	49 a	25 a	28 bc	23 a	25 ab
N-120 (F)	87 b	91 b	86 cd	88 b	39 b	37 b	34 b	37 c	21 a	24 c	20 a	22 b
LSD (5%)	13	11	15	11	5	4	7	3	7	7	9	7

N-0 (F) = T_1, (0 kg N ha^{-1} flat planting), N-0 (B) = T_2, (0 kg N ha^{-1} bed planting), N-60 (B) = T_3, (60 kg N ha^{-1} bed planting), N-80 (B) = T_4, (80 kg N ha^{-1} bed planting), N-100 (B) = T_5, (100 kg N ha^{-1} bed planting), N-120 (B) = T_6, (120 kg N ha^{-1} bed planting), N-120 (F) = T_7, (120 kg N ha^{-1} flat planting).

by grain was observed even with 80 kg N ha^{-1} application on beds than with 120 kg ha^{-1} application in flat planting. Similarly, higher N uptake in straw was also observed with 100 and 120 kg N ha^{-1} applications in bed planting than with 120 kg ha^{-1} application in flat planting. Overall, higher N accumulation in grain and straw was observed under bed planting than under conventional flat planting (Table 2). The application of 120 kg N ha^{-1} in bed planting led to 25% and 32% higher N accumulation in grain and straw, respectively, than did flat planting at the same rate of N application (Fig. 2).

3.3. N use, recovery, and agronomic efficiency

The maximum N use efficiency (62 kg kg^{-1}) was found with the application of 60 kg N ha^{-1} in bed planting followed by 80, 100, and 120 kg N ha^{-1} applications, whereas the minimum N use efficiency (37 kg kg^{-1}) was found with the application of 120 kg N ha^{-1} in flat planting (Table 3). The application of 120 kg N ha^{-1} in bed planting led to 15.02% higher N use efficiency than N application at the same rate in flat planting. Similarly, greater N recovery efficiency was observed in bed planting than in flat planting. The highest N recovery efficiency (1.19, 1.18, and 1.06 kg kg^{-1}) was observed with the applications of 80, 100, and 120 kg N ha^{-1} in bed planting and the minimum (0.82 kg kg^{-1}) was observed in flat planting with 120 kg N ha^{-1} application (Table 3). Similarly, higher N agronomic efficiency (30 kg kg^{-1}) was observed with the application of 80 kg N ha^{-1} in bed planting (Table 2). Comparison of bed and flat planting showed that 29.83% higher N recovery and 14.59% higher N agronomic efficiency were observed for bed than for flat planting at the same rate of N application (Fig. 2).

3.4. Cost–benefit ratio

Three years of pooled wheat grain and straw yield data were used for calculating cost–benefit ratios. The analysis showed that the highest cost–benefit ratios were achieved by N application at 120, 100, and 80 kg ha^{-1} in bed planting, followed by 120 kg N ha^{-1} application in flat planting (Table 4). Economic analysis showed a 15% higher return in bed than in flat planting when N fertilizer was not applied, in the T1 and T2 treatments. However, the economic return was 29% higher in bed than in flat planting when N fertilizer was applied at 120 kg ha^{-1}. Evaluation of the economic returns of N doses applied on beds showed an increasing trend from no fertilizer to 120 kg N ha^{-1} application.

Table 3 – Effect of planting method and nitrogen dose on nitrogen recovery and use efficiency.

Treatment (kg N ha^{-1})	N recovery efficiency (kg kg^{-1})				N use efficiency (kg kg^{-1})			
	Year 1	Year 2	Year 3	Pooled	Year 1	Year 2	Year 3	Pooled
N-0 (F)	–	–	–	–	–	–	–	–
N-0 (B)	–	–	–	–	–	–	–	–
N-60 (B)	0.95 c	1.06 b	1.04 a	1.02 c	63 a	60 a	62 a	62 a
N-80 (B)	1.19 ab	1.25 a	1.13 a	1.19 a	58 a	58 a	54 b	57 a
N-100 (B)	1.27 a	1.13 ab	1.13 a	1.18 ab	51 b	48 b	45 c	48 b
N-120 (B)	1.13 b	1.02 b	1.03 a	1.06 bc	44 c	43 bc	41 cd	43 b
N-120 (F)	0.81 d	0.89 c	0.75 b	0.82 d	38 d	38 c	36 d	37 c
LSD (5%)	0.13	0.12	0.21	0.13	6	5	6	5

N-0 (F) = T_1, (0 kg N ha^{-1} flat planting), N-0 (B) = T_2, (0 kg N ha^{-1} bed planting), N-60 (B) = T_3, (60 kg N ha^{-1} bed planting), N-80 (B) = T_4, (80 kg N ha^{-1} bed planting), N-100 (B) = T_5, (100 kg N ha^{-1} bed planting), N-120 (B) = T_6, (120 kg N ha^{-1} bed planting), N-120 (F) = T_7, (120 kg N ha^{-1} flat planting).

Table 4 – Comparison of cost–benefit ratios for bed and flat planting.

Treatment (kg N ha^{-1})	Cost of urea fertilizer per hectare (Rs.)	Total expenditure (Rs.)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Gross income per hectare (Rs.)	Cost-benefit ratios
N-0 (F)	0	47,116	1816	3111	51,351	1.09
N-0 (B)	0	47,116	2100	3282	58,606	1.24
N-60 (B)	4435	51,551	3706	5994	103,919	2.02
N-80 (B)	5913	53,029	4533	6867	125,968	2.38
N-100 (B)	7391	54,509	4804	7676	134,498	2.47
N-120 (B)	8870	55,986	5123	8174	143,396	2.56
N-120 (F)	8870	55,986	4454	7967	126,825	2.27

N-0 (F) = T_1, (0 kg N ha^{-1} flat planting), N-0 (B) = T_2, (0 kg N ha^{-1} bed planting), N-60 (B) = T_3, (60 kg N ha^{-1} bed planting), N-80 (B) = T_4, (80 kg N ha^{-1} bed planting), N-100 (B) = T_5, (100 kg N ha^{-1} bed planting), N-120 (B) = T_6, (120 kg N ha^{-1} bed planting), N-120 (F) = T_7, (120 kg N ha^{-1} flat planting).

4. Discussion

4.1. *Effect of planting method and nitrogen dose on economics and on wheat grain yield and its attributes*

Bed planting along with N fertilizer application rates from 0 to 120 kg ha^{-1} was compared with flat planting with 120 kg N ha^{-1} application because of varying fertilizer spreading area. The efficient use of applied N supports increased grain yield and reduced the cost of crop production. Owing to the superior grain yield and lower N fertilizer expenditure, a higher gross income and cost–benefit ratio were achieved in bed than in flat planting (Table 4). Similarly, ref. [25] reported higher gross income and cost–benefit ratio for bed than for flat planting. The present study found a higher grain yield from planting wheat on beds than from the conventional flat planting, owing to higher N uptake, N recovery efficiency, number of grains per spike, and 1000-grain weight (Fig. 2). In flat planting the N fertilizer is broadcast uniformly, but in bed planting, about one third of the applied N is collected in beds during their construction, given that initially fertilizer is broadcast and then beds are made by taking soil from furrows on the beds. In this way, beds receive a higher concentration of nitrogen fertilizer. Grain yield increased in bed planting compared to flat planting mostly because of deposition of more fertile topsoil on beds and because weeds were also concentrated mainly in furrows owing to the lack of crop cover there and the higher moisture content under the changed land configuration. Bed planting also reduced the soil surface exposed to flooding, eliminating surface soil crusting on top of the bed where wheat was planted. In bed planting, the microclimate within the field was also changed by orientation of the wheat plants in rows on top of the beds, and created favorable soil conditions for mineralization of native as well as applied nutrients. Similarly references [26,27] found that planting of wheat on beds increased grain yield up to 21% over flat planting.

4.2. *Nitrogen use efficiency and its components*

Wheat bed planting with an application of 120 kg N ha^{-1} showed 15%, 14%, and 29% higher N use and agronomic and recovery efficiencies, respectively, compared with flat planting with the same rate of N application, as a result of higher grain yield and N uptake in plant dry matter (Fig. 2). The higher uptake of N under the bed planting system was associated with greater biomass production of crops and lower loss of applied fertilizer [28]. In bed planting, higher N use and agronomic and recovery efficiencies were observed because about one third of applied N fertilizer is also added on beds during their construction, given that initially fertilizer is broadcast and then beds are made by taking soil from furrows on the beds, leaving more fertile top soil on beds under the changed land configuration than under flat planting. The higher fertilizer use efficiency in bed planting was attributed mainly to accumulation of fertile topsoil on beds, weeds infestation in furrows and mineralization of native as well as applied nutrients [25,28]. Similarly, higher nitrogen contents in wheat biomass and chlorophyll content in flag leaves were recorded in bed than in flat planting, owing to greater N uptake and use efficiency [13]. Bed planting improved plant growth by providing better soil conditions than flat planting [29,25]. Similarly, ref. [13] reported that generally in flat planting after wheat germination, N fertilizer is applied normally by broadcasting on the soil surface and flood-irrigated, but that it can be band-applied into the furrows with bed planting, enhancing NUE. Bed planting of wheat resulted in increases in grain yield, N uptake in plant dry matter, and use efficiency.

5. Conclusions

From the three-year findings it can be concluded that wheat crop can be grown efficiently on beds and that grain yield and NUE can be increased by bed planting, relative to the conventional flat method. The three-year pooled data of the present study showed that wheat planting on beds and N application at 120 kg ha^{-1} led to 15% higher NUE and grain yield than did flat planting at the same rate of N application. Without loss of yield, about one third of the N fertilizer can be saved in bed planting of wheat compared to the flat method. There is a future need to cultivate wheat on beds instead of by flat planting, to increase wheat N use efficiency and grain yield.

Acknowledgments

We are very thankful to Professor Dr. Rai Niaz Ahmad, Ex-Dean, Faculty of Agricultural Engineering and Technology, University of Agriculture, Faisalabad Pakistan, for providing a wheat bed planting drill and also to the reviewers for the improvement of this manuscript.

REFERENCES

[1] M.A. Malik, M. Irfan, Z.I. Ahmed, F. Zahoor, Residual effect of summer grain legumes on yield and yield components of wheat (*Triticum aestivum* L.), Pak. J. Agric. Eng. Vet. Sci. 22 (2006) 9–11.

[2] Ministry of Food, Agriculture and Livestock, Federal Bureau of Statistics, Government of Pakistan, Economic Survey of Pakistan 2012–13, 2013.

[3] N. Sarwar, M. Maqsood, K. Mubeen, M. Shehzad, M.S. Bhullar, R. Qamar, N. Aqbar, Effect of different levels of irrigation on yield and yield components of wheat cultivars, Pak. J. Agric. Sci. 47 (2010) 371–374.

[4] R.A. Fischer, K. Sayre, I.O. Monasterio, The effect of raised bed planting on irrigated wheat yield as influenced by variety and row spacing, Australian Centre for International Agriculture Research Proceeding 121, of a workshop on "Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico", 1–3 March, 2005, Grifith, NSW, Australia, 2005.

[5] K.D. Sayre, O.H. Moreno Ramos, Applications of raised-bed planting systems to wheat, CIMMYT Series: CIMMYT Wheat Program Special Report, 31, 1997.

[6] L. Ortega, A. Sayre, K.D., C.A. Francis, Wheat nitrogen use efficiency in a bed planting system in northwest Mexico, Agron. J. 92 (2000) 303–308.

[7] W.R. Raun, J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, E.V. Lukina, Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application, Agron. J. 94 (2002) 815–820.

[8] A. Rehman, M.F. Saleem, M.E. Safdar, S. Hussain, N. Akhtar, Grain quality, nutrient use efficiency, and bio economics of maize under different sowing methods and NPK levels, Chil. J. Agric. Res. 4 (2011) 586–593.

[9] T. Kichey, B. Hirel, E. Heumez, F. Dubois, J. Le-Gouis, Winter wheat, post-anthesis nitrogen uptake and remobilization to the grain correlates with agronomic traits and nitrogen physiological markers, Field Crops Res. 102 (2007) 22–32.

[10] M. Iqbal, M.J. Akhtar, W. Mohammad, S.M. Shah, H. Nawaz, K. Mahmood, Effect of tillage and fertilizer levels on wheat yield, nitrogen uptake and their correlation with carbon isotope discrimination under rain fed conditions in north-west Pakistan, Soil Tillage Res. 80 (2005) 47–57.

[11] S. Yadvinder, E. Humphreys, S.S. Kukal, B. Singh, Amanpreet Kaur, S. Thaman, A. Prashar, S. Yadav, J. Timsina, S.S. Dhillon, N. Kaur, D.J. Smith, P.R. Gajri, Crop performance in permanent raised bed rice-wheat cropping system in Punjab, India, Field Crops Res. 110 (2009) 1–20.

[12] D.R. Huggins, W.L. Pan, Nitrogen use efficiency component analysis: an evaluation of cropping system differences in productivity, Agron. J. 85 (1993) 898–905.

[13] W. Fahong, W. Xuqing, K. Sayre, Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China, Field Crops Res. 87 (2004) 35–42.

[14] A. Hameed, A.K. Solangi, Water management strategies for area with poor drainage or shallow water table conditions, Proceedings of Irrigation System Management Research Symposium, Lahore, Pakistan, April 11–13, 1993.

[15] E.O. Mclean, Soil pH and lime requirement, in: A.L. Page, R.H. Miller, D.R. Keeney (Eds.), Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties, 2nd editionAmerican Society of Agronomy, Soil Science Society of America, Madison, WI, USA, 1982, pp. 199–209.

[16] D.L. Rowell, Soil Science: Methods and Application, Longman Scientific & Technical, UK, 1994.

[17] G.J. Bouyoucos, Hydrometer method for making particle analysis of soil, Agron. J. 54 (1962) 464–465.

[18] J. Ryan, G. Estefan, A. Rashid, Soil and plant analysis laboratory manual, 2nd edition International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, 2001.

[19] M.L. Jackson, Soil Chemical Analysis, Prentice-Hall Inc., Englewood Cliffs, New Jersey, USA, 1962.

[20] A. Rehim, M. Hussain, M. Abid, M.Z. Haq, S. Ahmad, Phosphorus use efficiency of *Triticum aestivum* L. as affected by band placement of phosphorus and farmyard manure on calcareous soils, Pak. J. Bot. 44 (2012) 1391–1398.

[21] A.R. Dobermann, Nitrogen use efficiency-state of the art, Paper presented at the IFA International Workshop on Enhanced-Efficiency Fertilizers, Frankfurt, Germany, June 28–30, 2005.

[22] N.K. Fageria, V.C. Baliger, C.A. Jones, Growth and Mineral Nutrition of Field Crops, 2nd edition Marcel Dekker, Inc., New York, USA, 1997.

[23] R.G.D. Steel, J.H. Torrie, D.A. Dickey, Principles and Procedures of Statistics: a Biometrical Approach, 3rd edition McGraw Hill Co., New York, USA, 1997.

[24] CIMMYT, An Economic Training Handbook, Economic Program, CIMMYT, Mexico, 1988.

[25] I. Hassan, Z. Hussain, G. Akbar, Effect of permanent raised beds on water productivity for irrigated maize-wheat cropping system, Australian Centre for International Agriculture Research Proceeding 121, of a workshop on "Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico", 1–3 March, 2005, Grifith, NSW, Australia, 2005.

[26] M.I.U. Mollah, M.S.U. Bhuiya, M.H. Kabir, Bed planting: a new crop establishment method for wheat in rice-wheat cropping system, J. Agric. Rural Dev. 7 (2009) 23–31.

[27] M.I. Hossain, C. Meisner, J.M. Duxbury, J.G. Lauren, M.M. Rahman, M.M. Meer, M.H. Rashid, Use of raised beds for increasing wheat production in rice-wheat cropping systems, New directions for a diverse planet: proceedings of the 4th International Crop Science Congress, 26 Sep.–1 Oct., 2004, Brisbane, Australia, 2004.

[28] M.L. Jat, R. Gupta, Y.S. Saharawat, R. Khosla, Layering precision land leveling and furrow irrigated raised bed planting: productivity and input use efficiency of irrigated bread wheat in indo-gangetic plains, Am. J. Plant Sci. 2 (2011) 578–588.

[29] S.S.H. Shah, A. Hassan, A. Ghafoor, A. Bakhsh, Soil physical characteristics and yield of wheat and maize as affected by mulching materials and sowing methods, Plant Soil Environ. 32 (2013) 14–21.