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Full Length Article

Nitrogen use Efficiency and Productivity of Barley as affected by Nitrogen and Sorghum Mulching in Different Cropping Systems

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Abstract

Nitrogen losses from the agricultural systems not only reduce crop yields, but could also impose adverse effects on environment. Although there is no quick fix to immediately reduce these losses; however, improving nitrogen use efficiency (NUE) through controlled mineralization would be helpful for sustainable management of the losses. This study was conducted to evaluate the influence of nitrogen (N) application and sorghum mulch on the performance and NUE of barley under different cropping systems. Barley was planted in fallow, maize and alfalfa vacated fields. Nitrogen was applied at 0, 50 and 100 kg N ha^{-1} with or without sorghum mulch under maize-barley, alfalfa-barley and fallow-barley cropping systems. The contribution of soil N from the preceding crop had a considerable influence on the productivity of barley. Barley grain yield was higher in maize-barley cropping system than fallow-barley and alfalfa-barley cropping systems. Application of N at 50 kg ha^{-1} had the highest agronomic NUE, which declined with further increase in N, indicating its potential loss to the environment. However, production efficiency, sink capacity, and economic profitability were higher from N application at 100 kg ha^{-1}. Although there was no significant influence of sorghum mulch on the barley productivity, it helped to reduce the nitrification rate, as more NH_4^+ and less NO_3^- contents were noted with mulch application. The study reports useful information about the potential use of sorghum mulch for suppression of nitrification. However, high cost associated with mulch may render it unacceptable to farmers, unless favorable price policy is devised.

Keywords: *Hordeum vulgare*; Crop productivity; Nitrogen use efficiency; Sorghum mulch

Introduction

The maintenance of nitrogen use efficiency (NUE) has become critical to contribute towards agricultural and environmental objectives. Continuous addition of fertilizers or amendments is indispensable for proper nutrient supply and maximizing crop yields (Fageria, 2014). However, intensive N application results in rapid accumulation of mineral NO_3^-, which would not be efficiently retained by the soil matrix, can leach down to the soil profile or will be lost to environment through denitrification (Wang *et al.*, 2011). Deciding right amount of N for different crops is important because an excess of N would induce lodging in different crops, including barley and reduce the yield (Anbessa and Juskiw, 2012). Besides this, the issues of leaching and denitrification losses cannot be underestimated (Maqsood *et al.*, 2016), as both affect ecosystem, human health and global climate (Cassman *et al*., 2002; Coskun *et al.*, 2017). Therefore, slowing down the nitrification and denitrification process is inevitable under these circumstances (Jabran *et al.*, 2013). Many plant species, including some agronomic crops like sorghum, have the potential for biological nitrification inhibition (Jabran and Farooq, 2012; Subbarao *et al.*, 2007, 2012; Cheng and Cheng, 2015).

Barley is a low nutrient requiring crop, sensitive to N supply and its area under cultivation has continuously declined in Pakistan (Alley *et al.*, 2009; Naheed *et al.*, 2015). The cultivation of a crop without determining its response to the previous crop in the rotation could have drawbacks of unnecessary costs or limitations to yield (Tanaka *et al.*, 2010), since land in the previous crop varies in tillage practices, fertilizer input and irrigation inputs (Shahzad *et al*., 2016a, b). In this context, consideration of residual mineral N-credit from proceeding crops or fields i.e., fallow, maize, and alfalfa would drive useful information for N management in barley under sorghum mulch application. Therefore, incorporation of barley in the existing cropping systems would require assessment of its adaptation and productivity response (Tanaka *et al.*, 2010; Agegnehu *et al.*, 2014). However, there is no information available for barley from these perspectives. Another objective of this study was to improve the adaptation and productivity of barley under different cropping systems of Pakistan. So, what seemed to be important here is to find a

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suitable rotation and balance in N availability, while at the same time improving NUE, and productivity of barley without affecting the environmental quality.

Therefore, this study was conducted to evaluate the response of barley to different N levels and sorghum mulch in terms of productivity, NUE and economic returns in different cropping systems. Optimizing N levels for higher economic returns and inferring the role of sorghum mulch to lower N losses was the other major objective of the study.

Materials and Methods

Experimental Site and Soil

This study was carried out at Agronomic Research Farm, University of Agriculture, Faisalabad, Pakistan (longitude 73º8`E, latitude 31º8`N, and altitude 184 m), during two consecutive barley growing seasons (November–April) in 2014–2015 and 2015–2016. The soil was sandy loam, aridicol, classified as Lyallpur soil series by soil taxonomic classification, USDA (Nawaz *et al.,* 2016). The information relating to previous crops and N status of the soils under different cropping systems have been given in Table 1. Alfalfa was being grown as a perennial crop to feed the animals, but its plant population declined gradually (<10 plants m^{-2}) in the subsequent years due to weed infestation. Therefore, alfalfa field was vacated for barley plantation in October. The period of fallow cultivation is from April to October each year. Maize was cultivated from August–November in each year. The three fields were managed in October-2014 and 2015 for a two-year study of barley.

The climate of the experimental site is semi-arid, with subtropical conditions and an average annual rainfall of 200 mm. The climatic data were collected from the agricultural meteorology cell located at a 100 m distance from the experimental site. The mean maximum and minimum temperatures during the barley growing season (October/November-April) were 26.1°C and 5.9°C, respectively. January was the coldest month with 2°C temperature, while April was the hottest month with a peak temperature of 40.5°C in each growing season. The rainfall received was 145 mm in 2014–2015 and 116.5 mm in 2015–2016. Relative humidity varied from 75.3% in January to 43.9% in April.

Experimental Details

The seeds of barley (cv. Haider-93) were obtained from Wheat Research Institute, Faisalabad, Pakistan. The previous crops (maize, alfalfa) and a 6-month fallow field were managed to represent different cropping systems, i.e., (i) fallow-barley (ii) maize-barley, and (iii) alfalfa-barley. The experimental treatments consisted of 3 different N doses (0, 50 and 100 kg ha^{-1}) and 2 sorghum mulch levels (no mulch or 4 t ha^{-1}). The net plot size was 2 m × 6 m. The experiment was laid out according to randomized complete block design with split-split plot arrangement. Cropping systems were taken as main plot, mulch as sub-plot and N levels as sub-subplots. The seeds were planted with a single row hand drill in 25 cm apart rows on November 25 in 2014 and November 23, in 2015. The seed rate was kept 75 kg ha^{-1}. Barley was harvested on April 5 and April 7 during 2015 and 2016, respectively.

Preparation of Sorghum Mulch

Sorghum was harvested at maturity and dried under shade. The whole plants, including leaves, stem and fruiting heads were sliced into 1.25–2.5 cm pieces. The prepared mulch was surface applied after first irrigation to avoid any risk to crop emergence.

Observations and Calculations

Barley biomass and grain yield were determined from whole plots in each replication of each treatment. The harvested crop was sun-dried before threshing to estimate dry matter and grain yield. Flag leaf area (cm^2) measurements were made from 10 leaves at the pre-anthesis stage through Image J program. Digital images of 10 randomly selected leaves were taken at pre-anthesis stage for flag leaf area measurements. The images were taken with black background and placing a scale with the leaves. The taken images were then processed in Image J for area measurements (Ahmad *et al.,* 2015).

Harvest index was the ratio of grain yield to biomass yield. Grain protein% was determined through Omeg analyzer G (Bruins Instruments, USA), by using 600 g clean and dust free grain samples. Each value was an average of 3 samples run for protein determination. Chlorophyll contents of green leaves were measured from 10 leaves by using an At LEAF+ instrument (FT Green LLC Wilmington, USA) and index values were averaged for statistical analysis. Straw and grain N was determined by the micro-Kjeldahl procedure (Bremner and Mulvaney, 1982).

Production efficiency, sink capacity, agronomic NUE (Jun-Hua *et al.*, 2010) and NHI (Haider *et al.*, 2015) were calculated according to the following formulas:

$$\text{Sink capacity } (10^7) = \text{Spikes counted in unit area } \times \text{grain number per spike}$$

$$\text{Production efficiency } (\text{kg ha}^{-1}\text{day}^{-1}) = \text{Biomass produced } (\text{kg ha}^{-1})/\text{crop duration (days)}$$

$$\text{Agronomic nitrogen use efficiency } NUE_A (\text{kg kg}^{-1}) = \frac{\text{Grain yield}_F \text{ (kg)} - \text{Grain yield}_c \text{(kg)}}{\text{Fertilizer nutrients applied (kg nutrient)}}$$

Where F=N fertilized crop and C is a non-fertilized crop.

$$\text{Nitrogen harvest index (NHI \%)} = (\text{Grain N uptake }/\text{total plant N uptake}) \times 100$$

$$\text{Total residual mineral nitrogen} = \text{Total residual } NO_3^-\text{–N} = D_i \times BD_i \times [NO_3^-] \times 0.1$$

Where D_i represents, soil depth in cm; BD_i is the bulk density of g cm^{-3}; $[NO_3^-]$ is the soil nitrate nitrogen, concentration in mg kg^{-1}. Here 0.1 is the conversion factor. Similarly, the NH_4^+ was also determined by following the same procedure.

Mineral N (NH_4^+ and NO_3^-) Estimation

Soil extractions for ammonium (NH_4^+) and nitrate (NO_3^-) were made from the 10 g of soil by using 100 mL of 2M KCl solution and shaking them at 100 rpm for 1 h. The filtrate for ammonium concentration was analyzed by indophenol blue method (Motsara and Roy, 2008). Nitrate estimation was carried out calorimetrically by following the phenoldisulphonic acid method. The soil sampling for the estimation of mineral $NH_4^+$and $NO_3^-$was carried out, after 15 days of N-application at tillering stage of barley.

Economic Analysis

The cost effectiveness of any applied method can be measured based on net-benefits, net returns and the benefit-cost ratio (BCR). The economic analysis was done to estimate the profitability of different treatments used in the study. The grain yield was reduced by 10% to adjust it at farmers' level (Byerlee, 1988). The variable cost included the cost of mulching, N, and threshing. While the fixed cost included the costs incurred on land rent, seeds, fertilizers costs excluding the N treatment, sowing operations, crop husbandry and labor. BCR was calculated by dividing net benefits by total expenditure incurred.

Statistical Analysis

The collected data were tested for normality before conducting the statistical analyses. The data were found normal, therefore original data were used in the analyses. The difference between the experimental runs (years) was tested first using a paired t-test. Significant differences were observed among experimental runs; therefore, data of each run was analyzed separately. Fisher's Analysis of variance (ANOVA) technique was used to test the significance of the data (Steel *et al.*, 1997). Least significant difference test at 5% probability was used to separate the means, whereas ANOVA indicated significance. A combined linear regression analysis was conducted between yield and production efficiency and sink capacity across the years. All analyses were done on Statistix-10 (Analytical Software, Tallahassee, FL, USA).

Results

Crop Productivity

Flag leaf area was significantly altered by the individual (except cropping systems) and interactive effects cropping systems, N rates and sorghum mulch (Table 2). The highest flag leaf area was observed under no-mulch condition during both years of study. Similarly, the highest flag leaf area was recorded under 100 kg N application during each year of the study.

Grain yield was significantly influenced by cropping systems and N rates during 1st year, while cropping systems, sorghum mulch and N rates notably altered grain yield during 2nd year of the study (Table 2). Regarding interactions, cropping system × mulch, and cropping system × mulch × N rates interactions remained non-significant during both years of the study. Straw yield was significantly influenced by cropping systems and N rates, while mulch had no effect in this regard during each year of the study (Table 2). The maize-barley cropping system observed the highest grain and straw yields during both years (Table 2). Similarly, the highest grain and straw yields were noted under 100 kg N, while the lowest yields were observed under control treatment in both years (Table 2). Chlorophyll index was significantly altered by N rates, whereas cropping systems and mulch had no effect in this regard (Table 2). The highest chlorophyll index was noted under 50 and 100 kg N rates, while the lowest was observed under no application of N.

The production efficiency and sink capacity were significantly influenced by cropping systems and N application; however mulch had no effect in this regard (Table 3). The highest sink capacity and production efficiency was recorded for maize-barley cropping system and 100 kg N rate, while alfalfa-barley cropping system and no application of N resulted in the lowest production efficiency and sink capacity during each year of the study (Table 3). The harvest index did not differ among cropping systems and mulching treatments as well as across the years. However, harvest index was significantly increased by 50 kg N during 2015–2016 (Table 3). Grain yield had a significant positive correlation with sink capacity (R^2=0.81, 0.85, n=18) and production efficiency (R^2=0.99, 0.99, n=18), during 2014–2015 and 2015–2016, respectively and it derived a useful information for estimation of yield (Fig. 1).

Grain Protein and NUE

The accumulation of grain protein was significantly influenced by cropping systems, mulching and N rates during 1st year, while only N application influenced grain protein accumulation during 2nd year of the study (Table 4). The highest grain protein was recorded for maize-barley cropping system during 1st year, while no difference was observed among cropping systems during 2nd year of the study. Highest nitrogen use efficiency was observed in fallow-barley and alfalfa-barley cropping systems during 1st year and fallow-barley cropping system during 2nd year. Barley had the higher N uptake under maize-barley cropping system in both years. However, mulch application did not play a significant role in N uptake. The highest N uptake was observed under 100 kg N application. Nitrogen harvest index was highest in alfalfa-barley cropping system, while the lowest was observed in fallow-barley and maize-barley cropping systems.

Table 1: Previous crop details and soil characteristics of experimental sites

	Previous crop/field	Field management duration	Biomass yield (t ha^{-1})	Soil N applied (kg ha^{-1})	Residual soil N (Before sowing of barley)			Organic matter (%)	Phosphorus (ppm)	Potassium (ppm)	EC (dS cm^{-1})	Soil pH	Soil bulk density (g cm^{-3})
					NH_4^+ (mg/kg)	NO_3^- (mg/kg)	Total N (mg/kg)						
2014-15	Fallow	Six months	-	-	2.4	8.20	540	1.05	8.4	165	2.04	7.4	1.29
	Maize	Autumn maize	22.4	250	3.3	12.2	820	1.60	12.50	260	2.59	7.8	1.30
	Alfalfa	03-years	-	-	2.6	6.80	500	1.06	9.4	160	2.12	7.5	1.31
2015-16	Fallow	Six months	-	-	2.3	6.42	422	1.04	6.4	180	2.14	7.7	1.28
	Maize	Autumn maize	19.05	250	3.0	8.10	620	1.29	9.4	200	2.45	7.6	1.32
	Alfalfa	04 Years	-	-	2.7	6.40	480	0.98	6.8	146	1.92	7.5	1.30

Table 2: Influence of nitrogen application, and sorghum mulch on flag leaf area, grain yield, straw yield, and chlorophyll index of barley in the different cropping system

Treatments	Flag leaf area (cm^2)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Chlorophyll index	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Cropping system (CS)								
Fallow-barley	86.36±3.49	76.12±2.48	2363±106 b	2181±115 b	4800±234 b	4336±230 b	46.24±1.15	47.67±0.61 b
Maize-barley	89.94±3.51	77.35±3.02	2527±75 a	2371±94 a	5269±152 a	4757±138 a	43.22±1.26	51.11±0.84 a
Alfalfa-barley	77.55±3.49	67.50±2.90	2231±113 b	2211±98 b	4652±216 b	4265±204 b	43.00±0.98	47.50±0.91 b
Mulching (M)								
Non-mulch	91.16±2.77 a	78.46±2.12 a	2360±78	2218±76 b	4883±147	4388±149	44.63±1.11	48.48±0.78
Mulch	78.03±2.66 b	68.85±2.35 b	2387±89	2291±94 a	4926±195	4517±175	43.85±0.79	49.03±0.67
Nitrogen levels (N)								
N_0	73.19±1.84 c	63.22±1.61 c	1850±57 c	1679±38 c	3967±142 c	3523±126 c	40.62±0.96 b	46.17±0.85 b
N_{50}	88.82±2.92 b	75.90±2.40 b	2523±44 b	2436±39 b	5105±146 b	4607±95 b	45.69±1.08 a	49.50±0.83 a
N_{100}	91.84±4.21 a	81.85±2.84 a	2747±40 a	2649±34 a	5649±94 a	5228±96 a	46.12±1.04 a	50.61±0.61 a
CS	ns	ns	**	**	*	**	ns	*
M	**	**	ns	*	ns	ns	ns	ns
N	**	**	**	**	**	**	**	**
CS×M	*	ns	ns	ns	*	ns	ns	ns
CS×N	**	ns	**	ns	*	*	ns	ns
M×N	**	ns	*	*	ns	ns	**	ns
CS×M×N	**	*	Ns	ns	ns	ns	ns	ns

Each value indicates mean of three replications ± standard error
*significance at $p<0.05$, ** significance at $p<0.01$, ns=non-significant
Means sharing the same letter, for a parameter during a year, don't differ significantly $p<0.05$
N_0= Control (non-fertilized), N_{50}= 50 kg N ha^{-1}, N_{100}= 100 kg N ha^{-1}

Table 3: Influence of nitrogen application, and sorghum mulch on production efficiency, sink capacity, and harvest index of barley in the different cropping system

Treatments	Production efficiency (kg ha^{-1} day^{-1})		Sink capacity (×10^7 ha^{-1})		Harvest index (%)	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Cropping system (CS)						
Fallow-barley	19.70±0.89 b	18.17±0.96 b	15.93±0.69 b	13.79±0.69 ab	30.87±0.74	34.33±0.79
Maize-barley	21.06±0.63 a	19.77±0.79 a	18.24±0.95 a	14.42±0.95 a	30.16±0.33	33.29±0.60
Alfalfa-barley	18.60±0.94 c	18.06±0.82 b	14.35±0.76 c	12.81±0.76 b	30.09±0.51	33.45±0.52
Mulching (M)						
Non-mulch	19.67±0.65	18.58±0.63	16.82±0.60	13.41±0.60	30.49±0.36	33.62±0.45
Mulch	19.90±0.75	18.75±0.78	15.52±0.73	13.93±0.73	30.26±0.53	33.77±0.60
Nitrogen levels (N)						
N_0	15.42±0.47 c	13.99±0.31 c	11.09±0.28 c	9.52±0.28 c	29.71±0.67	32.47±0.55 b
N_{50}	21.03±0.37 b	20.02±0.32 b	17.00±0.36 b	14.77±0.36 b	30.91±0.43	35.04±0.65 a
N_{100}	22.90±0.33 a	21.98±0.28 a	20.43±0.44 a	16.73±0.44 a	30.49±0.52	33.58±0.61 ab
CS	**	**	**	*	ns	ns
M	ns	ns	ns	ns	ns	ns
N	**	**	**	**	ns	*
CS×M	ns	ns	ns	ns	ns	ns
CS×N	**	ns	*	**	ns	ns
M×N	*	**	*	*	ns	ns
CS×M×N	ns	ns	ns	ns	ns	ns

Each value indicates mean of three replications ± standard error
*significance at $p<0.05$, ** significance at $p<0.01$, ns=non-significant
Means sharing the same letter, for a parameter during a year, don't differ significantly at $p<0.05$
N_0= Control (non-fertilized), N_{50}= 50 kg N ha^{-1}, N_{100}= 100 kg N ha^{-1}

Soil Nitrogen Dynamics

Both ammonium (NH_4^+) and nitrate contents (NO_3^-) were significantly affected by cropping systems, mulching and N application (Fig. 2 and 3). The NH_4^+ and NO_3^- contents differed between mulch and no-mulch plots, which are of particular interest in our study. The mulching resulted in more NH_4^+ retention than no-mulch treatment with 50 and 100 kg N rate in each cropping system (Fig. 2).

Table 4: Influence of nitrogen application, and sorghum mulch on grain protein, agronomic NUE, N uptake and nitrogen harvest index of barley in different cropping system

Treatments	Grain protein (%)		Agronomic NUE (kg kg^{-1})		N uptake by crop (kg ha^{-1})		N harvest index (%)	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Cropping system (CS)								
Fallow-barley	11.67±0.24 b	12.04±0.25	12.47±1.32 a	13.85±1.26 a	38.20±1.72 b	35.26±1.87 b	69.92±2.31 b	69.84±2.43 b
Maize-barley	12.43±0.28 a	12.93±0.24	8.62±0.81 b	10.94±0.57 b	40.84±1.22 a	38.33±1.53 a	66.15±1.70 c	66.15±1.87 c
Alfalfa-barley	10.37±0.26 c	12.66±0.17	12.57±1.18 a	10.48±1.14 b	36.05±1.83 c	35.02±1.59 b	78.60±3.72 a	79.34±3.66 a
Mulching (M)								
Non- mulch	11.79±0.29 a	12.55±0.21	10.01±0.90 b	10.40±0.99 b	38.15±1.26	36.04±1.23	72.13±2.29	72.13±2.41
Mulch	11.15±0.23 b	12.54±0.18	12.44±0.97 a	14.44±0.77 a	38.58±1.45	36.37±1.52	70.99±2.54	71.42±2.55
Nitrogen levels (N)								
N_0	10.38±0.23 c	11.70±0.18 c	-	-	29.91±0.92 c	27.14±0.61 c	83.38±3.11 a	83.15±3.24 a
N_{50}	11.70±0.30 b	12.60±0.18 b	13.48±0.56 a	15.15±0.91 a	40.79±0.72 b	38.89±0.62 b	69.36±1.30 b	69.52±1.68 b
N_{100}	12.41±0.26 a	13.33±0.17 a	8.97±0.42 b	9.70±0.50 b	44.40±0.65 a	42.64±0.55 a	61.93±1.25 c	62.66±1.45 c
CS	**	ns	**	**	**	**	**	**
M	**	ns	**	**	ns	ns	ns	ns
N	**	**	**	**	**	*	**	**
CS×M	ns	ns	**	**	ns	**	**	**
CS×N	ns	**	**	**	**	ns	**	**
M×N	*	ns	*	**	*	*	**	**
CS×M×N	ns	*	ns	*	ns	ns	**	**

Each value indicates mean of three replications ± standard error
*significance at $p<0.05$, ** significance at $p<0.01$, ns=non-significant
Means sharing the same letter, for a parameter during a year, don't differ significantly at $p<0.05$
N_0= Control (non-fertilized), N_{50}= 50 kg N ha^{-1}, N_{100}= 100 kg N ha^{-1}

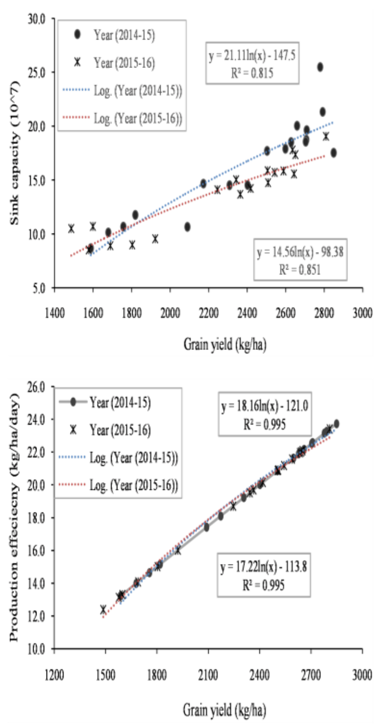

Fig. 1: Relationship of grain yield with production efficiency and sink capacity of barley

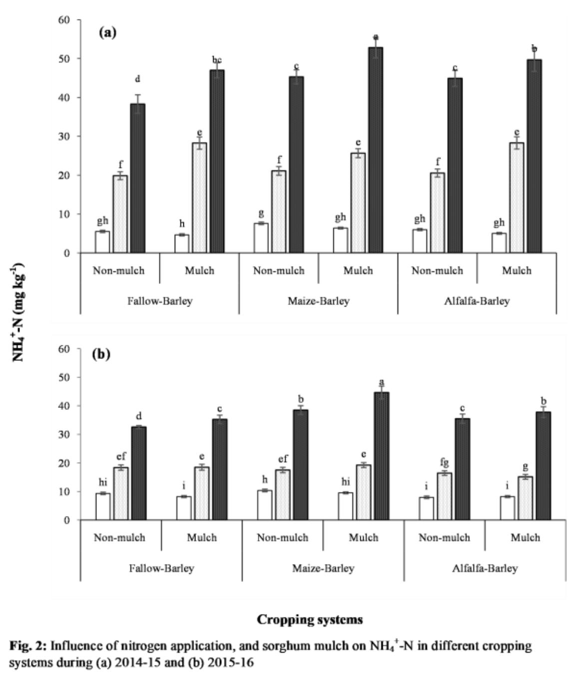

Fig. 2: Influence of nitrogen application, and sorghum mulch on NH_4^+-N in different cropping systems during (a) 2014-2015 and (b) 2015-2016

While NO_3^- contents remained higher in the no-mulch treatment than mulch application in fallow-barley and alfalfa-barley cropping systems. However, in maize-barley cropping system, it remained statistically similar (Fig. 3). The maize-barley cropping system had higher NH_4^+ accumulated under the sorghum mulch at 100 kg N application (Fig. 2a and b) during both years. Similarly, NO_3^- contents were also higher in the maize-barley CS, at 100 kg N application (Fig. 3a and b).

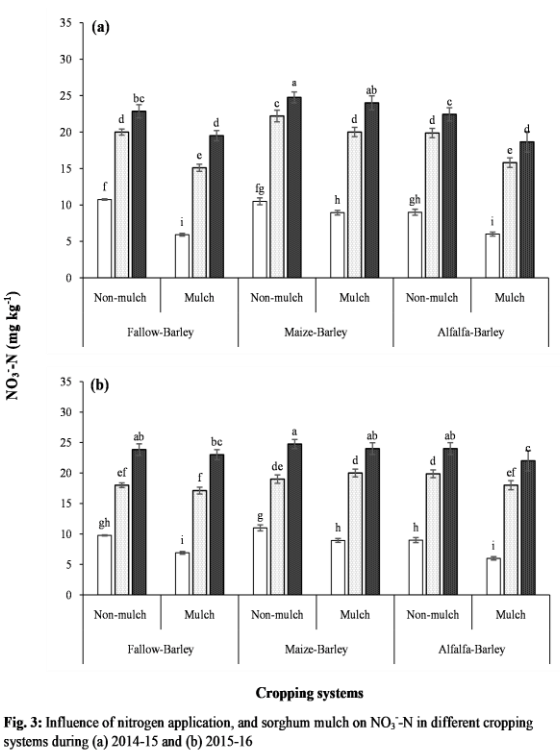

Fig. 3: Influence of nitrogen application, and sorghum mulch on NO_3^--N in different cropping systems during (a) 2014-2015 and (b) 2015-2016

Economic Analysis

The cultivation of barley in maize-barley cropping system realized more monetary benefits (520 $) than fallow-barley and alfalfa-barley cropping systems (461$ and 419$, respectively). The BCR analysis revealed that 100 kg N would be required for barley crop, after the harvesting of alfalfa without the mulch application. However, a little difference among BCR of 50 and 100 kg N application suggested that lower rate (50 kg) could be a suitable application with equal economic advantages in the fallow-barley and maize-barley cropping systems, and without mulch application.

Discussion

This study indicated that overall maize-barley cropping system was better than rest of the cropping systems in terms of grain yield, straw yield and chlorophyll index (Table 1). Although, alfalfa is an N fixing crop; it resulted in less productivity than maize-barley and fallow-barley cropping system (Table 2 and 3). Under the certain situations, the results might be quite different and dependent on the site-specific conditions as observed in the current study. The legitimate reason was the management of alfalfa in growing regions of Pakistan. Typically, alfalfa stands are maintained for longer periods (10–15 years) (Jefferson *et al.,* 2005), but in Pakistan, its plant population emaciates within few years due to weed infestation. Therefore, the stands are terminated after 3–4 years, as observed on this site. Moreover, alfalfa is usually harvested at intervals to feed animals in several cuts. Haque and Jakhro (2013) concluded that alfalfa field would not reflect positive contributions in soil N-credit, if continuously harvested for animal feeding. Therefore, the productivity was lower in alfalfa-barley cropping system than the rest of the cropping systems (Table 1). Maize-barley cropping system, due to intensive cultural practices in the maize and residual fertilizer levels could result in more N mineralization (Raiesi, 2006). Maize was also supplied with higher amounts of other macronutrients i.e., phosphorus and potassium and therefore this system had a distinct advantage over other cropping systems due to residual N, P and K levels for the barley crop (Table 1). The fallow-barley cropping system had low residual fertility level than maize-barley cropping system; therefore, resulted in similar trend as of alfalfa-barley cropping system (Table 2). Similarly, the comparison of cropping systems for production efficiency and sink capacity also showed the same trend (Table 3). The grain protein accumulation was more in maize-barley cropping system, as it showed more N uptake than other systems, while NHI and NUE were lower in the maize based system. Fageria (2014) associated this lower efficiency with N losses by volatilization, leaching, and denitrification, where fertilizer is applied in large amounts. This indicates maize based system was less efficient in utilizing N, as it had more residual levels. NHI indicates N uptake transported to the grain (Fageria and Baligar, 2005) and therefore, we can say alfalfa based cropping system showed efficient utilization of nitrogen (Table 3).

The sorghum contains phenolics and it can attract a great deal of attention in the scientific communities, which suppress the activity of nitrifying organisms i.e., Nitrosomonas and Nitrobacter (Jabran *et al.,* 2013; Subbarao *et al.,* 2006; Coskun *et al.,* 2017). Therefore, it could be assumed that sorghum mulch would minimize rapid accumulation of nitrate and save the potential losses to the environment further through leaching and denitrification. This also suggested the potential use of mulch for its controlled NO^-_3 release and availability for the longer period (Jabran *et al.,* 2013). In other words, it is an indication to reduce the risk of nitrate leaching and in sustaining the N availability (Subbarao *et al.,* 2012; Coskun *et al.,* 2017). In this study, mulch application retained more NH_4^+ and less NO^-_3 as compared to the no-mulch condition (Fig. 2 and 3). The lower NH_4^+ concentrations under no-mulch conditions indicated rapid mineralization, as opposite to mulch conditions, where it was halted. This depression in the N transformations indicated the nitrification inhibition potential of sorghum mulch. Therefore, higher NUE under mulching is the consequence of the controlled mineralization of fertilizer (Gentile *et al.,* 2009).

Table 5: Economic analysis for the influence of nitrogen application and sorghum mulching on barley in different cropping systems

CS	M	Nitrogen	Grain yield	Straw yield	Gross income	Cost of fertilizer	Cost of mulch	Cost of threshing	Cost that varies	Fixed cost	Total expenditure	Net returns	BCR
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	
Fallow-barley	M_0	N_0	1538	3810	862	0	0	56	56	654	710	153	1.14
		N_{50}	2190	4693	1170	36	0	80	115	654	769	401	1.37
		N_{100}	2361	5194	1272	71	0	86	157	654	811	461	1.37
	M_1	N_0	1460	3302	793	0	111	53	164	654	818	-25	0.77
		N_{50}	2257	5045	1222	36	111	82	229	654	883	339	1.12
		N_{100}	2467	5419	1328	71	111	90	272	654	926	402	1.14
Maize-barley	M_0	N_0	1843	4261	1009	0	0	67	67	654	721	288	1.31
		N_{50}	2310	5490	1277	36	0	84	120	654	773	503	1.50
		N_{100}	2442	5598	1333	71	0	89	160	654	814	520	1.44
	M_1	N_0	1751	4358	984	0	111	64	175	654	829	155	0.98
		N_{50}	2362	5450	1292	36	111	86	233	654	887	406	1.19
		N_{100}	2520	5611	1363	71	111	92	274	654	928	435	1.17
Alfalfa-barley	M_0	N_0	1515	3663	842	0	0	55	55	654	709	133	1.11
		N_{50}	2049	4295	1087	36	0	74	110	654	764	323	1.28
		N_{100}	2300	4918	1227	71	0	84	155	654	809	419	1.33
	M_1	N_0	1424	3353	785	0	111	52	163	654	817	-32	0.76
		N_{50}	2247	4413	1168	36	111	82	229	654	882	286	1.06
		N_{100}	2415	5163	1289	71	111	88	270	654	924	365	1.10

Barley grain price is 14.54 US \$ per 40 kg; Straw price 3.18 US\$ per 40 kg; Yield is adjusted to 10% less than actual; CS=cropping system; M=mulching; Mo is without mulch; M_1= Sorghum mulch (4 ton=111 \$); US \$= 110 Rs. N_0= Control (non-fertilized), N_{50}= 50 kg N ha^{-1}, N_{100}= 100 kg N ha^{-1},Cost of threshing= 10% of the value of crop, Cost that varies= Costs associated with the treatments, Fixed cost=Costs that do not differ across the treatments, BCR=Benefit-cost ratio is a profitability index

Despite the positive influence of sorghum mulch on N dynamics and accompanied other benefits reported in various studies, it didn't increase the yield positively to the promising scale in this study (Erenstein, 2002; Shafi *et al.*, 2007; Cheema *et al.*, 2008). The mulch did not influence the production efficiency and sink capacity, N uptake and N harvest index (Table 3 and 4). The results do not provide a conclusive evidence about mulch effect on productivity, as it marginally affected the yield and yield components (Table 2). Another perspective might be that the soil moisture was not a limiting factor, as it remained sufficiently available for barley growth supplied through irrigation. Therefore, the mulch might not have prompted the positive effects on yield characteristics, as most scientists consider mulch for reducing the evaporation and for water use efficiency (Chen *et al.,* 2015). However, the present study suggested mulch application for influencing the N dynamics in a positive way.

All of the N application rates differed from each other significantly in flag leaf area production, grain and straw yield, production efficiency and sink capacity. The 100 kg N rate positively affected all the yield components. However, increase was not linear, as upper limits of genetic potential are achieved at some level earlier than 100 kg N in barley (Albrizio *et al.,* 2009). Therefore, higher application rates derived less NUE.

In our study, the increasing N fertility beyond a certain limit induced lodging of barley in the maize-barley cropping system and decreased yield and productivity, although the straw yield was retained (Matusinsky *et al.,* 2015). Therefore, intensive maize fertilization could pose a threat to the environment, as it has lesser NUE. Overall the cost-benefit analysis determined limited financial advantage to the grower of sorghum mulch, as it has shown a marginal agronomic advantage (Table 5). Therefore, its BNI potential benefits might not convince growers to adopt sorghum mulch application as a strategy, unless convinced for long-term sustainability benefits and rising climatic concerns.

Conclusion

The 50 kg N ha^{-1} can be recommended as the optimum rate of application for barley production. Although sorghum mulch (4 t ha^{-1}) improved the NUE; however, due to the high cost, it cannot be recommended to the growers for widescale adoption without any financial assistance to farmers. In the long run, sorghum mulching would be a good initiative for environmental quality protection and agriculture sustainability.

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