Growth and yield of barley (*Hordeum vulgare* L.) as affected by nitrogen and phosphorus fertilization and water regimes in Tigray, Ethiopia

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ABSTRACT

The understanding of the interactive effects of abiotic stresses is a crucial issue for improving cereal production in arid environment. For this reason, study was conducted in northern Ethiopia, Tigray region in three sites characterized by different climatic conditions during the cropping season of 2009/10 to understand the agronomic responses of the barley crop to nitrogen and phosphorus fertilization rates combined with supplementary irrigation. Nitrogen (N) and phosphorus (P) fertilizers were applied under three water regimes to 'Sasa' barley variety using split - split plot design with three replications where the sites were treated as a main plot, water regimes assigned to the sub-plot and N and P fertilizers to the sub-subplot. fertilizers and sites had significant (*$p<0.001$*) effect on grain yield, thousand grain weight (TGW) and phenological traits. Supplementary irrigation had no effect traits investigated. Most interaction effects, N×P, N×site and P×site had very significant to significant effects on studied barley traits. Supplementary irrigation × site interaction had significant effect only on thousand grain weight (TGW). Optimum yield, for each site, was obtained from different combination of N and P, implying the need of different recommendation package instead of the general 100 - 100 kg ha^{-1} UREA and DAP or combination of 28 and 20kg ha^{-1} of nitrogen and phosphorus fertilizers across all barley growing areas. Therefore, universal recommendation of 100 UREA and 100kg ha^{-1} DAP should not be treated as best production package for all barley growing areas and this study suggests further thorough investigation for specific NP fertilizers rate recommendation for different barley growing areas.

Keywords: Nitrogen, Phosphorus, Sasa, Phenological traits, Interactions, Grain yield, TGW, Arid environment.

1. INTRODUCTION

1.1. Background and rationale

Barley (*Hordeum vulgare* L.) is among the main crops grown on the rainfed highlands of Tigray, Ethiopia. However, barley yields are low, ranging from 0.8 to 1.8 t ha^{-1}, depending on the season and applied inputs (Fekadu and Skjelvåg, 2002). Abiotic stresses are such as water, nutrients and temperature are contributing factors to this low yielding of cereal crops. The difference between potentially expected average and actually recorded average yields was high due to these stresses. Sinebo et al. (2003) reported that about 65% of grain yield variability in barley was attributed to nitrogen stress. Yields of barley under each of N and P stresses are reported to be less than 50%

of those of the respective non-stressed environments (Cantero-Martínez et al., 2003; Atlin and Frey, 1989).

The poor soil fertility in northern Ethiopia has been blamed for limiting the production and production stability of barley (Fekadu and Skjelvåg, 2002) and nitrogen and phosphorus are among the most productivity limiting nutrients (Kho, 2000). Abourached et al. (2008) and Myers (1984) indicated that the amount of N fertilizer required under semiarid climate is largely dictated by the seasonal rainfall. As a result, lower rates of Urea (40 to 80 kg ha^{-1}) is recommended under water deficit conditions (Pandey et al., 2000). This implies that the response of crops to applied fertilizers varies from one site to another due to different conditions, mainly rainfall (Al-Kaisi and Yin, 2003; Gregory et al., 1997). Thus, such interactions should be taken into account when developing fertilizer recommendation packages for a particular area. Hence, the objective of this paper has been to evaluate the agronomic responses of the barley crop, in under Tigray conditions, to nitrogen and phosphorus fertilization rates combined with supplementary irrigation.

2. MATERIALS AND METHODS

2.1. Sites

The experiment was conducted in three locations: Mekelle University (MU) Research Station, Korem, and Atsbi during the growing season of 2009 (Table 1). Annual rainfall at Mekelle is bimodal with a short rainy season from February to March and the main rainy season from June to September. The soil has typically 36, 30, and 34 % of sand, silt, and clay, respectively (Habtegebrial et al., 2007). The rainfall distribution at Korem is relatively better, and sometimes it may reach 1200 mm a year. The soil frequently faces a water logging problem. The rainfall pattern at Atsbi is variable with high probabilities of late onset and early cessation. The fields at all test sites were flat and uniform in surface topography.

Table 1. Physiographic and climatic characteristics of the experimental sites

Site	*Lat (N)*	*Long (E)*	*Alt (masl)*	*Mean RF (mm)*	*Mean T(°C)*	*Soil type*	*Class*
Mekelle	13°14′	39°32′	2150	400 - 700	18.8	Clay loam	Cambisol
Korem	12°31′	39°31′	2450	700 – 800	22.5	Clay loam	Vertisol
Atsbi	14°06′	39°48′	2600	300 – 600	20.2	Sandy clay loam	Cambisol

Source: National Meteorology Agency (NMA), Mekelle branch, 2004.

2.2. Experimental treatments and design

The different rates of combined nitrogen and phosphorus fertilizers were tested under three water regimes using a split –split plot design with three replications at three sites. Site was considered as the main plot, water regime assigned to the subplots, and fertilizer rates to the sub-subplots. The size of the main plot and the sub-subplot was 252 and 6 m^2, respectively. Fertilization treatments comprised of a zero check and different rates of N and P fertilizers (100-100kg ha^{-1} DAP (46-18-0% NPK) and Urea (46%N), recommended for the sites). The zero check had 0-0 kg ha^{-1} of N and P, and the different fertilization treatments consisted of 14/10, 14/20, 14/30, 28/0, 28/10, 28/20, 28/30, 42/0, 42/10, 42/20, and 42/30 kg N/P ha^{-1}, respectively. Fertilization was done by applying two thirds of N and the full dose of P at sowing and the remaining one third of nitrogen after appearance of the first lateral tiller on the plants (Abourached et al., 2008; Lo´pez-Bellido et al., 2006; Mossedaq and Smith, 1994).

The three water regimes were as follows. 1) Twice supplementary irrigation, applied during tillering and flowering developmental stages, 2) a single supplementary irrigation during tillering, and 3) rainfed without any supplementary irrigation. Seeds of the cultivar Sasa were row planted at 20cm row spacing at a rate of 125 kg ha^{-1} at the normal sowing time of each site.

2.3. Data collection and statistical analysis

Phenological recordings such as days to booting and flowering were collected following the Zadoks growth scale (GRDC, 2005; Zadoks et al., 1974). Booting was defined to growth stage (GS) 45 (approximately flag leaf sheath opening) and flowering to GS 65 when 50% of the spikes flowered. Grain yield was harvested from 4 m^2 of six central rows, and 1000 grain weight was determined for each individual plot. Statistical analyses were conducted by using Proc GLM of SAS version 9.1 for analysis of variance of non-orthogonal data. Significance of effects was assessed using F-test and standard deviation. Duncan's Multiple Range Test (DMRT) was carried out to compare differences between treatment means.

3. RESULTS

3.1. Weather characteristics of the experimental sites

Pattern of rainfall were similar for the three sites (Fig. 1) during the main (*mehar*) rainy season (July - September), though MU and Korem sites received more rain during July and August than the Atsbi site. For this cropping season, the total rainfall was above the long-term average at all sites. *Belg* (short) rain (March and April) was good for MU and Korem and small for Atsbi site. The temperature levels of each site were within the range of their long term averages (data not presented).

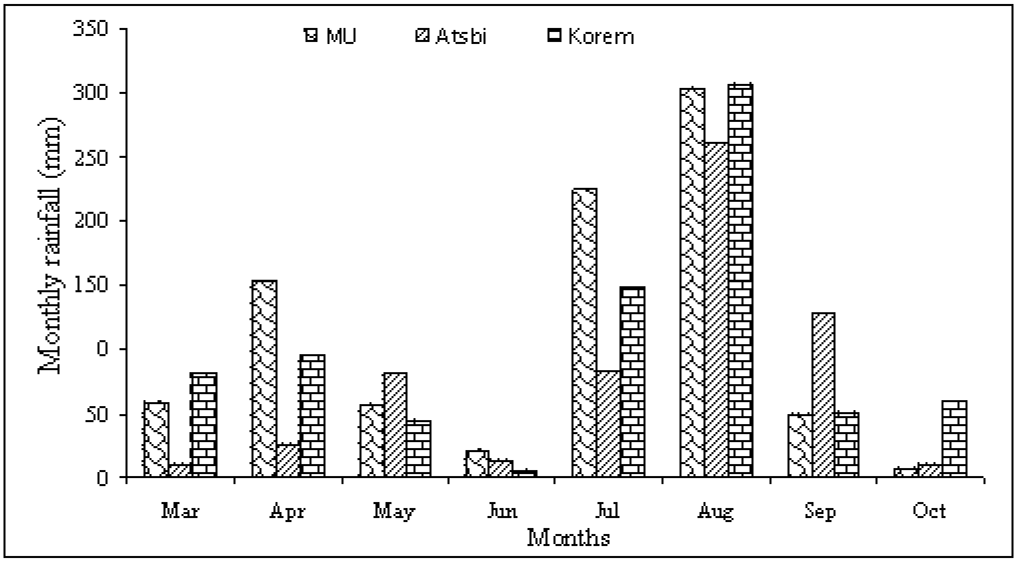

Figure 1. Rainfall distribution across months at the experimental sites during the 2009 cropping season.

3.2. Grain yield

Grain yield was highest at MU and lowest at the Korem site (Table 4). Irrigation showed no main or interaction effects on grain yield (Table 3). The increase in grain yield to increasing rates of nitrogen as compared with the check plot was about 900 to 1000kg per hectare at MU, 500 to 900 at Korem and 300 to 400 at Atsbi (Table 4). The maximum grain yield under MU condition and at the Atsbi site was obtained from plots treated with 14kg N ha^{-1}. In Korem, mean grain yield increased consistently up to the highest N rate of 42 kg ha^{-1}, (site x N) $p < 0.01$ (Table 3). Higher rates of nitrogen fertilization increased grain yields similarly at all sites (Table 2). The mean rate of yield increase was 12.6kg grain per kg nitrogen but the significant increase was between the check treatment and the fertilised ones (Table 2). The same was the case for the P treatments.

There was a significant interaction in grain yield between phosphorus and nitrogen fertilization rates (Table 3). Due to the non orthogonality of the experimental design it is not straightforward to make a fully consistent interpretation of this interaction (Table 3). However, relating to the check plots of 0/0 NP the increase in grain yield for higher P rates seems to be consistently higher at N rates of 28 than of 14 kg ha^{-1} (Table 2). A further increase to 42 kg ha^{-1} produced more irregular responses to both N and P rates. This may be related to more lodging at the highest rate of N fertilization, especially at MU (Table 4).

Table 2. Grain yield (100kg ha^{-1}) at check treatment (0/0 NP) and increases for various combinations of N and P fertilization rates. Mean values followed by different letters were significantly different at the 5 per cent probability level.

	kg N ha^{-1}				
kg P ha^{-1}	***0***	***14***	***28***	***42***	***Means***
0	12.9		+5.4	+6.4	16.9b
10		+6.3	+7.2	+6.6	19.6a
20		+5.6	+7.4	+9.9	20.5a
30		+8.3	+8.6	+6.6	20.8a
Means	12.9b	19.6a	20.1a	20.3a	

Table 3. Analysis of variance (ANOVA) for days from sowing to booting, days to flowering, grain yield, and grain weight of Sasa barley fertilised with nitrogen and phosphorus under three water regimes at three experimental sites of Tigray (Ethiopia) (wi. = nested within. *: $p < 0.05$, **: $p < 0.01$).

Source of variation		***Days to booting (days)***		***Days from booting to flowering (days)***		***Grain yield (100kg/ha)***		***TGW (g)***	
	Df	***MS***	***F***	***MS***	***F***	***MS***	***F***	***MS***	***F***
Site (sit)	2	314.5	248.6***	1400.3	907.4***	8139. 1	172.3**	1088.5	160.9***
Rep wi. sit (Error term I)	6	1.26		1.54		47.2		6.77	
Irrigation (Irr)	2	0.18	0.10ns	3.00	1.72ns	105.38	1.58ns	2.17	0.07 ns
sit×Irr	4	22.15	12.29***	6.52	3.73*	104.14	1.56ns	98.22	3.19*
RepxIrr wi. sit (Error term II)	12	1.80		1.75		66.65		30.77	
N	3	6.65	3.98**	0.28	0.18ns	224.26	10.48**	64.99	3.95**
P	3	13.33	8.01**	1.40	0.91ns	260.35	12.16**	46.08	2.80*
N×P	5	1.00	0.61ns	0.84	0.55ns	57.31	2.68*	51.90	3.16**
sit×N	6	8.63	5.19**	4.20	2.75*	69.39	3.24**	52.02	3.16**
sit×P	6	3.46	2.08*	1.79	1.17ns	25.52	1.19ns	53.57	3.26**
Irr×P	6	0.92	0.55ns	1.42	ns	7.18	0.335ns	2.56	0.15 ns
Irr×N	6	2.02	1.22ns	1.38	ns	33.91	1.58ns	10.24	0.62 ns
sit×Rep×Irr×N×P (Error term III)	262	1.66		1.53		21.40		16.44	

Table 4. Grain yield in 100kg/ha at different levels of nitrogen and phosphorus fertilization to Sasa barley at three sites. Mean values followed by different letters were significantly different at the 5 per cent probability level.

	N rate (kg/ha)					***P rate (kg/ha)***				
Site	***0***	***14***	***28***	***42***	***Means***	***0***	***10***	***20***	***30***	***Means***
MU	20.3	+10.6	+10.3	+8.9	29.4a	26.2	+4.2	+3.8	+4.7	29.4a
Korem	6.5	+5.1	+7.6	+8.9	13.3c	10.5	+2.71	+4.0	+5.2	13.3c
Atsbi	12.0	+4.4	+3.5	+4.2	15.7b	13.9	+2.0	+3.2	+1.9	15.7b

3.3. Thousand grain weight (TGW)

Grain weight was significantly higher at Mekelle (Tables 3 & 5). At this site irrigation increased grain size thought the increment was at decreasing rate from plots received single irrigation to those irrigated twice whilst more often it tended to reduce grain weight at Atsbi site compared to the check. Table 6 shows that grain weight was reduced by increasing rates of nitrogen as well as phosphorus. The significant interaction between N and P rates was more irregular but indicated a negative interaction by gradually larger reduction when higher rates of both nutrients were combined (Table 6). Figure 3a and b show that decreasing grain weight with increased rates of both nitrogen and phosphorus mostly was due to the Atsbi site, whilst Korem and MU showed no clear tendencies in TGW. Further the graphs show the higher TGW of MU (47.8 g) as compared with those of Korem and Atsbi (42.7 and 42.0 g, respectively) (*p<0.001*).

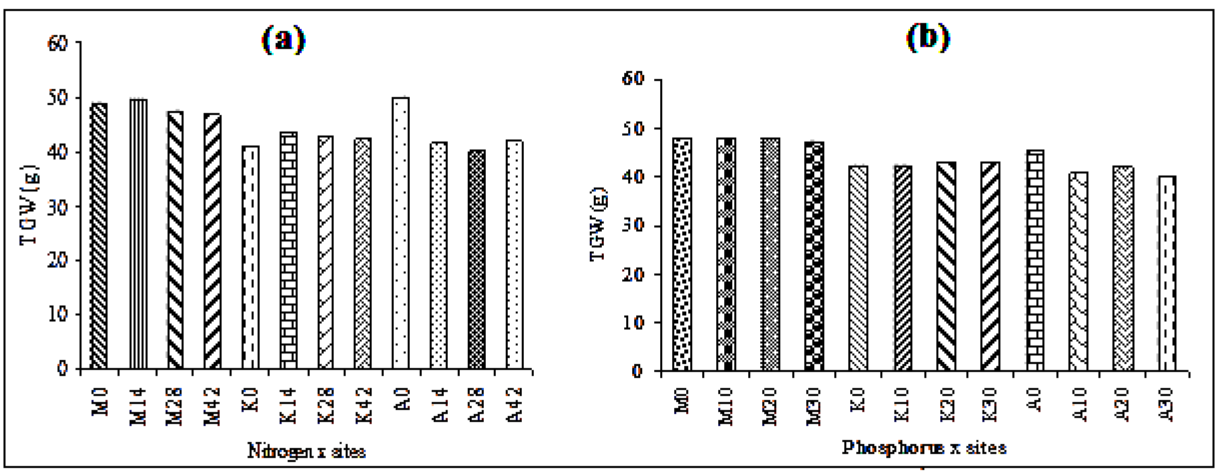

Figure 2. Effects of: a) nitrogen (0 to 42 kg ha^{-1}) and b) phosphorus (0 to 30 kg ha^{-1}) fertilization rates on grain weight of Sasa barley across three sites (M = Mekelle (MU), K = Korem, and A = Atsbi) in Tigray, Ethiopia.

Table 5. Thousand grain weight (g) of Sasa barley grown at three locations and irrigated once at first tillering and an additional time at flowering. Mean values followed by different letters were significantly different at the 5 per cent probability level.

	Irrigation			
Site	***No***	***Once***	***Twice***	***Means***
MU	46.06	+3.13	+2.16	47.82a
Korem	43.06	+0.32	-1.39	42.71b
Atsbi	42.96	-2.61	-0.21	42.02b

Table 6. Thousand grain weight (g) of Sasa barley grown at three locations and fertilised with different rates of nitrogen and phosphorus. Mean values followed by different letters were significantly different at the 5 per cent probability level.

	kg N ha^{-1}				
kg P ha^{-1}	***0***	***14***	***28***	***42***	***Mean***
0	46.63		-2.17	-2.32	45.13a
10		-2.01	-4.43	-2.22	43.74ab
20		-2.76	-1.66	-2.22	44.42ba
30		-0.78	-3.90	-4.84	43.44b
Mean	46.63a	44.78b	43.59b	43.72b	

Table 7. Number of days from sowing to booting of Sasa barley grown at three locations and fertilised by different rates of nitrogen and phosphorus. Mean values followed by different letters were significantly different at the 5 per cent probability level.

	kg N ha^{-1}				***kg P ha^{-1}***			
Site	***0***	***14***	***28***	***42***	***0***	***10***	***20***	***30***
MU	47.9	-0.5	+0.2	+0.7	48.4	-0.4	-0.5	-0.3
Korem	51.8	-2.4	-2.9	-2.4	50.5	-1.2	-1.3	-1.6
Atsbi	51.1	-0.2	+0.3	+0.9	51.9	-0.7	-0.9	-0.1
Means	50.3a	49.3b	49.5b	50.0a	50.3a	49.5b	49.4b	49.6b

3.4. Crop phenology

The shortest time to booting was observed at MU, whilst plants at Korem used one day more and at Atsbi three days more (Table 3). At MU irrigation delayed booting, at Korem it hastened, whilst at Atsbi the effect was close to be negligible. The time from sowing to booting took about one day shorter at nitrogen rates of 14 and 28 kg ha^{-1} than at rates of 0 and 42 kg ha^{-1} (Table 7). This and the statistically significant interaction with location (Table 2) were mainly due to the hastening effect of N fertilization at Korem, whilst the responses were much smaller and more irregular at the two other sites.

The time from sowing to booting took about one day shorter where phosphorus had been applied than on the check plot (Table 7). The statistically significant interaction with location (Table 3) was due to the stronger effect of P fertilization at Korem than at the two other sites (Table 7). The time from booting to flowering was about three times longer at Korem than at MU or Atsbi (Table 7). Irrigation slightly increased the duration of the period at Korem and Atsbi, whilst it slightly hastened the rate of development at MU ($p<0.05$). Korem had cooler temperature than both Atsbi and MU sites (*data not presented*). Similar finding was reported by Badaruddin et al. (1999) indicating that hotter environments elicit a greater response to applied treatments.

4. DISCUSSION

Crop productivity is the resultant of environmental effects such as fertilizer, water and other managements and genotypes response (Boyer, 1982). Applied fertilizers affected both the phenological traits and yielding potential of the barley in all experimental sites, and the result is in agreement with Lo´pez-Bellido et al. (2000, 1996); and Mohr and Schopfer (1995). The effect of nitrogen fertilizer on phenological characteristics of the crop could be due to its effect of promoting vegetative growth and tiller boosting capacity. Its shortage influences the phenological process particularly the vegetative and generative phases (Mirschel et al., 2005). The delayed booting and flowering at Korem site should be related to the cooler temperature of the site compared to the others as reported by Bernier (1988); and Stones et al. (1999) on maize.

Increasing the dosage of both fertilizers was not necessarily increase grain yield of the crop though significant increase was obtained over the check plot (Table 2). This could be associated with either the original fertility status of the soil or response of the crop to these fertilizers. Their interaction effect, however, had very significant effect on grain yield where yield increase as phosphorus increases (Table 2). This could be due to the effect of phosphorus on grain filling of the crop and use efficiency of other nutrients (Potarzycki 2009; Rodriquez et al., 1999). We found that increase in both N and P fertilizers rate resulted in lighter seed weight compared with the unfertilised plots which could be associated with the increase in seed number per spike (Table 6). The same findings were reported by Rasmussen et al. (1997); Cossani et al. (2009); and Lo´pez-Bellido et al. (2000). The higher the number of seeds per spike, the lighter the seeds will be due to competition among the seeds in a spike. The impact of N and P fertilizers on grain weight varied greatly across the three sites (Fig. 2). Gooding et al. (1999) also reported similar finding. Nitrogen fertilizer had significantly different effects on grain yield of Sasa barley. The yield increased as rate of N increased from 0 to 42kg/ha in Korem and Atsbi sites even though the trend of increment was inconsistent for Atsbi. Contrarily the crop responded differently in MU site. The increase over the control check (0kg/ha) decreased from 1061kg/ha to 895kg/ha as N rate increased from 14 to 42kg/ha (Table 4). This presumably associated with the lodging effect of Nitrogen fertilizer. Delin et al. (2005) found similar result for barley and wheat grown in five locations with different fertilization rates where higher dosage of N fertilizer did not increase yield on clayey soil. Each site has a maximum potential yield governed by its climatic and soil properties.

Grain yield has also shown varied significantly ($p<0.001$) in response of phosphorus fertilization across different sites (Table 2). The crop respond positively as P rate increased from 0 to 30kg/ha (Table 4). However, at Atsbi yield showed declining trend as rate of P increase from 20 to 30kg/ha. The maximum yield (1706kg/ha) was obtained at P rate of 20kg/ha. The non – significant interaction between irrigation and fertilizers and weak interaction of irrigation with sites (Table 2) could be related with the good rainfall condition both in amount and distribution during the peak growing season (July – September). Otherwise irrigation could have had positive interaction effect with both fertility treatment and site crop performance as reported by Albrizio et al. (2010); and Tavakkoli and Oweis (2004) on wheat. Finding of Cossani et al. (2009) also showed that productivity of applied fertilizer is achieved if only soil moisture is not limiting. Araya and Stroosnijder (2010) suggested that water conservation for barley farming is unnecessary when the seasonal rainfall is above 480 mm.

5. CONCLUSION

In the era of precision agriculture which aims at site specific management practices, it is important to investigate the response of crops to applied fertilizers across sites for site specific production package. This paper concludes that Sasa barley has differential response to both nitrogen and phosphorus fertilizers in different growing areas and under different growth conditions. For arid environment where early cessation of rainfall is more common, fertilizer application dosage has great implication on maturity period of crops. The response of Sasa barley to applied fertilizers was not similar in every production sites. Maximum grain yield in each of the experimental site was obtained from different combination of nitrogen and phosphorus fertilizers. This indicates that site -specific fertilizer recommendation is crucial for two reasons: a) to improve crop productivity and b) to maximize profit through cutting unnecessary production cost. The studies implied that application of 100kg ha^{-1} of both DAP and UREA or combination of 20 and 28kg ha^{-1} of nitrogen and phosphorus fertilizers, locally used rate, should not be accepted as universal optimal rate for the different barley growing areas. Therefore, we suggest further thorough investigation to recommend specific nitrogen and phosphorus rates to be combined for optimal barley yield in major barley growing areas including the current study areas. Absence of crop response to supplementary irrigation should be related to excess rainfall during the growing season beyond water requirements of the crop. Evaluating the yielding potential of crops in a given environment requires understanding of optimal nutrient and water interaction as it was hypothesized that potential yield achieved by removing all water and nutrient related stresses.

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