Effect of Nitrogen Levels on Growth and Yield of Wheat at Different Elevations under Rain-fed Conditions in Jebel Marra Highlands

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Abstract

A field experiment was conducted at two sites for two seasons, 2000-01 and 2002-03 at farmer's fields to investigate the effect of four nitrogen levels; 0, 20, 40 and 60 kg N/ha, at two elevations; Trongotonga at 2800 m above sea level (a.s.l.) and Gorlambang at 2300 m a.s.l. on growth and yield of three wheat cultivars; Debera, El Nelein and a local variety Donki, in Jebel Marra highlands. Results showed that nitrogen application significantly increased flag leaf area, plant height in both elevations. As for yield and yield components, a positive increase in grain yield was obtained as a result of nitrogen application. The pattern of response of spikelets per spike, seeds per spike, number of spikes per m^2 was similar to that of grain yield. Nitrogen fertilizer, generally, decreased the 1000-seed weight and harvest index. Nitrogen percentage of plants at 50% anthesis and grain nitrogen percentage increased gradually with increasing nitrogen levels. Generally, the crop at high elevation site, gave greater biomass yield, grain yield and yield components. El Nelein variety was the earliest to flower and mature and produced higher grain and biomass yields with increased N levels. The local variety Donki was the latest to flower and mature, and gave the lowest yield and yield components.

Introduction

The Jebel Marra highland is a massive isolated volcanic complex which rises up to 3000 m above sea level (a.s.l), thus creating a moderate climate for wheat production under rainfed conditions. Wheat in Jebel Marra is usually planted between June to mid-July and harvested in November or December. The average annual rainfall ranges from 500 mm to 1000 mm (Miche, 1986). Low soil fertility has been noticed as a major constraint to wheat production under rains. This is aggravated by the water erosion and farmers practice contour cultivation to minimize this soil erosion. The response of wheat to nitrogen fertilizer is quite variable. This variation has been attributed to differences in climate, soil, crop variety and husbandry practices (Gallagher and Biscoe, 1978a). Generally, early nitrogen application promotes tillering and leaf growth, whereas late application prolongs leaf area duration and expansion (Spierz, *et al,* 1984). The amount of nitrogen applied also affects the pattern of N uptake by the crop (Sylvester-Bradley, 1990b). However, Austin

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(1982) reported that nitrogen uptake by crops was linearly related to the level of its application. In the absence of N application, nitrogen uptake will depend on the availability of soil nitrogen which is determined by mineralization.

Wheat growing season in central Sudan is quite short, ranging from 100 to 110 days during November-February (El Ahmadi, 1994). It is mainly grown under irrigation and the conventional cultivars of wheat in the Sudan include Debera, El Nelein, Condor, Giza, Wadi El Nil and Sasareb. Rainfed practices are never practiced in central Sudan. Altitude plays an important role in the distribution of wheat growing areas as it affects both temperature and rainfall. This consequently influences the developmental phases of wheat (Gorfu, *et al.*, 2003). In Arsi region of Ethiopia, it was reported that wheat grown at high altitudes (2200-2700 m a.s.l) took longer days to anthesis and maturity, compared to elevations of 2000- 2200 m a.s.l. (Gorfu, *et al.,* 2003).

The objectives of this work were to investigate the effect of nitrogen fertilizer application on growth and yield of wheat at different elevations under rain-fed environments of Western Sudan.

Materials and Methods

A field experiment was conducted at two sites for two seasons, 2000-01 and 2002-03 at farmer fields to investigate the effect of nitrogen levels on growth and yield of wheat (*Triticum aestivum* L.) varieties grown at different elevations in Jebel Marra highlands under summer rain-fed conditions. The selected elevations were: Trongtonga at 2800 m a.s.l. and Gorlambang at 2300 m a.s.l. Three wheat varieties were used, namely: Debera, El Nelein and a local variety (Donki) as a test variety. Nitrogen was applied in the form of urea (46% N) at the rates of: 0, 20, 40 and 60 kg/ha. The experimental design was completely randomized design, replicated four times. The individual gross size of the plot was 1.6x7 m, whereas the net harvested size was 1.2x5 m. Seed rate was 120 kg/ha. All plots received phosphorus in the form of triple super phosphate (46% P_2O_5). Growth parameters measured included: flag leaf area, days to 50% flowering, duration of grain filling and plant height. The measured yield components were number of spikelets per spike, number of seeds per spike, thousand seed weight, number of spikes per m^2 and harvest index. Final biomass and grain yield per hectare were determined as well.

Results and Discussion

Crop Development

Results of the study showed that N application significantly increased flag leaf area and plant height at both elevations. A similar response was observed by Pearman *et al.,* (1977) who concluded that application of high rates of nitrogen to a range of cultivars resulted in a much larger flag leaf area at anthesis and that contributed to a grater portion of increased LAI. On the other hand, Sylues-Bradley (1990b) reported that plant height of cereals increased significantly and linearly with increased nitrogen application. However, no significant differences were detected between varieties in flag leaf area (Tables 1-4). Differences among varieties in plant height were highly significant ($P \geq 0.05$). The local variety Donki was the tallest whereas El Nelein was the shortest. One of the aims of plant breeders is to go for shorter cultivars in order to avoid lodging, as was stated by Austin (1982). Days to 50% flowering and duration of grain filling were significantly increased by application of nitrogen fertilizer. However, the differences among varieties in days to 50% flowering and duration of grain filling were significant ($P \geq 0.05$) and El Nelein was the earliest in flowering and Donki was the latest. Gallagher and Biscoe (1978a) reported that there was a genotypic variation among wheat cultivars to time of flowering. They also reported that high grain weight is associated with longer grain filling period. It was observed that crops at low elevation site were faster to reach anthesis, compared to those of high elevation. This was because temperatures at low elevation exceeded those of the higher elevation by about 3-4^{0}C. Similar results were obtained in Ethiopian highlands by Gorfu *et al,* (2003). Duration of grain filling period of El Nelein variety was the longest, followed by Debera (Tables 1-4).

Grain Yield

Analysis of variance showed that application of nitrogen resulted in sharp increases in harvested grain yield in both seasons and sites. However, at 60 kg N/ha, grain yield exceeded the control by 30% and 45% for the high and low elevations, respectively, in the first season. The crop followed the same trend in the second season. El Nelein variety significantly ($P \geq 0.05$) outyielded both Debera and Donki (Tables 1-4). This finding is in agreement with the work of Ishag and Mohamed (1995) who used different stability indices and found that El Nelein was consistently more stable across different environments. Ishag (1994) reported that El Nelein variety had longer awns, which is a considerable character for adaptation of wheat for hot environments. The crop yield at high elevation site was significantly greater than low elevation site by 24 and 53%, for the first and second seasons, respectively. This is mainly attributed to relatively lower temperatures of higher elevations which enhance wheat production. This is in line with the findings of Ishag (1994) who reported that high temperature during grain filling stage, resulted in lower rates of grain filling and 31% reduction in grain weight. On the other hand, Spiertz and Ellen (1978) showed that increase in grain yield from applied nitrogen was not due to an increase in seed weight, but to the kernel number per unit area. The increase in nitrogen level to 60 kg/ha significantly increased the yield of El Nelein cultivar, especially at the high elevation (Figure 1a and b). The three cultivars kept the same ranking of yield at both elevations. The results revealed a significant interaction between cultivars and site in the second season. Gofu *et al,* (2003) found a significant cultivar by location interaction in grain yield, biological yields and harvest index.

Biomass Yield

Nitrogen application resulted in 41 and 95% increases in biomass yield for the high and low elevation sites, respectively, in the first season (Tables 1-4). Differences among varieties in biomass yield were not significant in the first season, whereas in the second season, Debera and El Nelein outyielded Donki. Biomass yield of high elevation site was found to be significantly greater than low elevation site by 46 and 63% for the first and second seasons, respectively (Tables 1-4). Austin (1982) pointed out that the potential production of biomass varies with genotypes and that biomass yield of the cooler temperature of higher elevation, was greater than that of low elevation sites.

Yield Components

Tables 1, 2, 3 and 4 showed that application of nitrogen fertilizer significantly ($P \geq 0.05$) increased number of spikelets per spike, seeds per spike and number of spikes per m^2. The progressive increment in number of spikelets per spike was clearly observed for Debera and El Nelein cultivars (Figure 2a). The response of the local cultivar Donki in the spikelets number was negative at the highest level of nitrogen (60 kg/ha). On the other hand, Langer and Liew (1973) reported that number of spikelets per spike and seeds per spike depend on florets initiation. Barling (1980) found that the number of spikes/m^2 highly responded to nitrogen application. On the other hand, thousand seed weight and harvest index were negatively influenced by nitrogen application (Tables 1-4). El Nelein variety had the highest number of spikelets per spike, seeds per spike, thousand seed weight and number of spikes per m^2. Yield components of high elevation sites were greater than those of low sites (Tables 1-4).Gallagher and Biscoe (1978b) found that variation in environmental factors could have a profound influence in the spikelets initiation and differentiation and grain set. Seed yield per spike was more dependent on the number of fertile spikelets/ spike and the number of grains per fertile spikelets (Hay and Walker, 1989).

Nitrogen percentage in plant material and grains

Nitrogen percentage at 50% flowering increased significantly ($P \geq 0.05$) from 0.97 and 0.84% at zero nitrogen level to 1.20 and 1.11% at the 60 kg N/ha level for the high and low elevation sites, respectively (Tables 1-4). Differences among varieties in N% of plant material at 50% flowering was significant only at the low elevation site in the second season where Donki gave the highest N%.There were significant differences ($P \geq 0.05$) between sites in the first season in N% at flowering, which ranged between 1.07% for high elevation to 0.95% for the low site but no significant differences were detected in the second season. Sylvester-Bradley *et al,* (1990b) reported that increasing nitrogen rates resulted in an increase of plant nitrogen at anthesis. They attributed this to nitrogen uptake by leaves and sheaths just before anthesis. Nitrogen percentage of the grains increased significantly ($P \geq 0.05$) in both seasons and sites with increasing N level. In the first season, N% level in the grains increased from 1.52% and 1.45% at the rate of zero N, to 1.77 and 1.74% at the 60 kg N/ha for high and low elevation sites, respectively (Tables 1-4). Similar results were found by Austin (1982) who observed increased total grain protein percentage in wheat with increased amounts of N fertilization. There were differences among genotypes in grain N%. El Nelein variety, which was of high yield potential, showed a low percentage of protein compared with the other varieties. Hay and Walker (1989) found that, in general, genotypes with high yield potential have a high nitrogen use efficiency (yield/N supply) as a result of high nitrogen utilization efficiency (yield/nitrogen uptake); but there was a negative association between genotype yield potential and protein content of the grain, a parameter that is important in grain quality.

Recommendations

1. Rainfed wheat growing is recommended at both elevations in Jebel Marra.
2. El Nelein is the most suitable variety for both elevations.
3. Nitrogen at the of 40 kg/ha is recommended to maximize wheat yield.

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Table 1. Effect of nitrogen levels on growth and yield of wheat varieties grown at different elevations in Jabel Marra highlands-Trongotonga site, season 2000-01.

Nitrogen level (kg/ha)	Flag leaf area (cm^2)	Days to 50% flowering	Duration of grain filling (days)	Plant height (cm)	No.of spikelets/ spike	No.of seeds/ spike	1000 seed wt (g)	No. of spikes/m^2	Harvest index (%)	Biomass yield (kg/ha)	Grain yield (kg/ha)	Plant N % at 50% flowering	Grain N %
0	19.3	73	38	81	16.9	25	41	315	39	6101	2193	0.97	1.52
20	19.9	74	39	83	17.5	27	39	335	36	7104	2444	0.99	1.55
40	20.0	74	40	87	18.2	27	38	360	36	7534	2516	1.11	1.69
60	20.8	75	39	90	18.8	28	39	364	35	8625	2834	1.20	1.77
S.E.±	0.89	0.17	0.13	2.1	0.72	0.77	1	24	1.1	857	198	0.05	0.08
Varieties													
Debeira	20.2	74	38	78	18	26	38	338	38	7194	2533	1.09	1.56
ElNelein	20.4	67	42	75	17.6	29	41	348	40	7502	2749	1.07	1.62
Donki	19.4	81	37	103	17.9	26	38	346	33	7326	2206	1.05	1.63
Site	20	74	39	85	17.8	27	39	344	36	7341	2497	1.07	1.63
S.E.±	0.77	0.14	0.11	1.8	0.41	0.69	0.87	21	36	743	172	0.04	0.06

Table 2: Effect of nitrogen levels on growth and yield of wheat varieties grown at different elevations in Jabel Marra highlands, Gorlambang site, season 2000-01.

Nitrogen level (kg/ha)	Flag leaf area (cm^2)	Days to 50% flowering	Duration of grain filling (days)	Plant height (cm)	No. of spikelets /spike	No. of seeds/ spike	1000 seed weight (g)	No.ofspikes/ m^2	Harvest index (%)	Biomass yield (kg/ha)	Grain yield (kg/ ha)	Plant N % at 50% flowering	Grain N %
0	11.7	67	34	68	14.3	27	40	265	42	3568	1670	0.84	0.45
20	13.9	66	34	72	15.0	26	40	306	41	4332	1685	0.83	1.52
40	15.4	68	34	80	15.9	27	39	323	39	5105	2044	1.01	1.58
60	18.1	69	35	85	17.5	28	38	346	39	6993	2539	1.11	1.74
S.E.±	1.145	0.14	0.14	2.7	0.77	1.34	0.82	31	0.835	715	275	0.06	0.09
Varieties													
Debeira	20.2	67	33	70	14.9	27	39	305	39	4605	1891	0.98	1.60
Elnaliar	20.4	61	39	70	17.0	29	41	299	44	4810	2085	0.95	1.55
Donki	19.4	74	31	89	15.3	24	38	330	57	5585	2018	0.92	1.61
S.E.±	0.99	0.13	0.14	2.4	0.66	1.2	0.75	38	0.73	619	238	0.04	0.07
Site	14.8	67	34	76	15.7	27	39	311	40	5000	1998	0.95	1.75

Table 3: Effect of nitrogen levels on growth and yield of wheat varieties grown at different elevations in Jabel Marra highlands, Trongotonga site, season 2002-03.

Nitrogen level (kg/ha)	Flag leaf area (cm^2)	Days to 50% flowering	Duration of grain filling (days)	Plant height (cm)	No.of spikelets /spike	No.of seeds/ spike	1000 seed wt.(g)	No.of spikes/ m^2	Harvest index (%)	Biomass yield (kg/ha)	Grain yield (kg/ha)	Plant N % at 50% flowering	Grain N %
0	19.3	69	37	82	17.0	33	40	328	38	4771	1822	0.90	1.43
20	20.1	70	38	83	18.0	34	39	353	37	6253	2320	0.96	1.55
40	21.3	71	38	85	18.0	35	38	362	36	6970	2531	1.10	1.66
60	21.8	71	39	88	19.0	37	37	365	36	7258	2649	1.22	1.76
S.E.±	0.48	0.15	0.14	0.75	0.77	0.75	0.29	20	0.23	284	100	0.05	0.08
Varieties													
Debeira	20.4	68	38	77	18.0	34	36	334	35	6690	2357	1.07	1.65
ElNelein	21.2	66	42	72	18.0	36	42	375	41	7089	2962	1.04	1.54
Donki	20.3	75	35	104	17.0	34	38	348	33	5161	1708	1.03	1.62
SE±	0.41	0.13	0.12	0.65	0.66	0.61	0.26	353	0.10	324	116	0.04	0.06
Site	20.7	70	38	84	18	35	0.26	21	36	6313	2331	1.05	1.60

Table 4: Effect of nitrogen levels on growth and yield of wheat varieties grown at different elevations in Jebel Marra highlands-Gorlambang site, season 2002=03.

Nitrogen level(kg/ha)	Flag leaf area (cm^2)	Days to 50% flowering	Duration of grain filling (days)	Plant height (cm)	No.of spikelets/ spike	No.of seeds/ spike	1000 seed wt.(g)	No. of spikes/m^2	Harvest index (%)	Biomass yield (kg/ha)	Grain yield (kg/ha)	Plant N % at 50% flowering	Grain N %
0	14.2	63	32	67	15.3	28	40	265	40	2985	1199	0.82	1.44
20	15.6	63	32	71	17.7	28	40	289	40	3610	1427	0.84	1.54
40	16.5	64	33	39	17.0	28	40	311	39	4481	1761	1.11	1.74
60	16.7	65	33	83	17.4	29	39	312	39	4481	1761	1.11	1.74
S.E.±	0.27	0.14	0.15	1	0.14	0.14	0.23	18	0.32	179	103	0.06	0.10
Varieties													
Debeira	14.6	61	31	70	16.1	28	39	312	39	4326	1679	1.20	1.60
ElNelein	17.0	59	37	72	17.7	30	41	305	42	4098	1731	1.03	1.55
Donki	15.6	71	29	84	16.7	27	39	265	37	3130	1151	1.11	1.66
S.E.±	0.23	0.12	0.13	0.9	0.12	0.14	0.20	17	0.29	155	121	0.07	0.08
Site	15.7	69	33	75	16.6	28	39	294	40	3851	1520	0.97	1.60

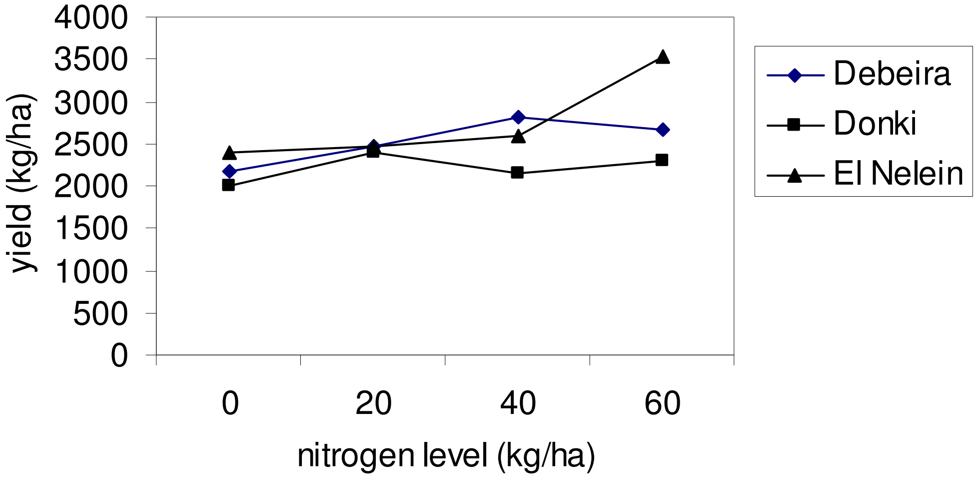
Table 5. Monthly rainfall record (mm) at Trongtonga and Gorlambang sites (2000, 2001and 2002).

Site / Month	Trongtonga Site			Gorlambang Site		
	2000	2001	2002	2000	2001	2002
April	19.5	10.5	-	-	50.0	9.0
May	58.5	72.5	59.0	25.0	17.0	14.5
June	114.5	124.5	120.5	131.5	65.5	98.5
July	248.5	229.0	277.0	187.0	148.0	197.0
August	306.0	267.0	388.0	276.5	261.5	257.5
September	62.0	51.0	177.5	85.5	63.5	107.5
October	15.0	-	27.0	-	21.0	11.0
Total	824.0	754.5	1049.0	705.5	626.5	695.0

Table 6. Mean air temperature (^{0}C) at Trongtonga and Gorlambang sites (2000, 2001 and 2002).

Site / Month	Trongtonga Site			Gorlambang Site		
	2000	2001	2002	2000	2001	2002
July	17.2	18.7	18.3	23.3	22.3	24.5
August	16.7	16.5	17.5	21.6	20.2	23.0
September	17.5	17.0	17.8	20.0	19.0	21.3
October	18.0	18.0	19.0	21.5	21.5	20.7
November	15.4	16.5	17.3	19.0	18.9	19.9
December	14.0	15.3	16.3	17.6	17.8	17.5
Mean	16.5	17.0	17.7	20.5	20.0	21.1

Fig. 1.Response of wheat cultivars to nitrogen
a)Trongtonga



b) Gorlambang

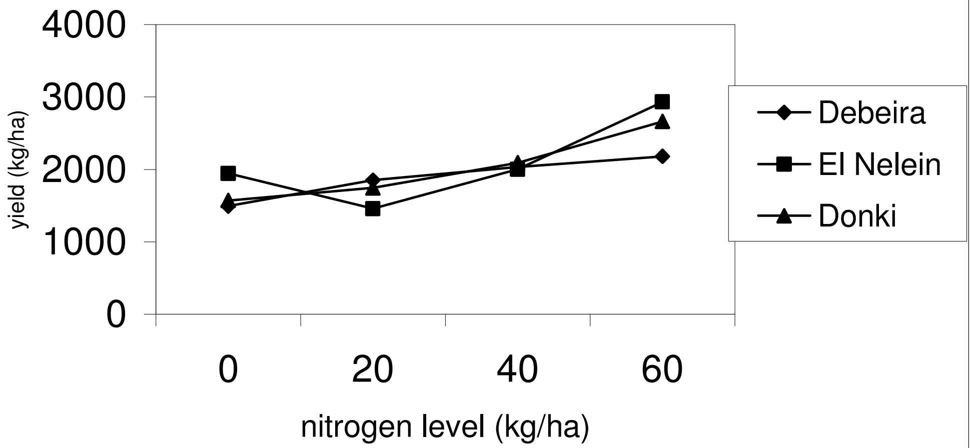


Fig 2 Effect of nitrogen on number of spikelets/spike of wheat cultivars