

## RESPONSE OF BREAD WHEAT TO RATE AND TIMING OF NITROGEN APPLICATION IN A MARGINAL RAINFALL ZONE IN ETHIOPIA

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### ABSTRACT

Nitrogen fertilizer rate by timing trials were conducted on bread wheat (*Triticum aestivum* L.) in peasant farmers' fields during two annual cropping seasons for three years in a drought-prone district of southeastern Ethiopia. Nitrogen rates had an incremental effect on grain yield, but the response to N was economically acceptable only up to 41 kg N ha<sup>-1</sup>, and then only in the more reliable second growing season. Mean grain yields obtained in different growing seasons were correlated with seasonal rainfall totals, but nitrogen response was not. Early application of N, either all at sowing or split applied between sowing and mid-tillering, resulted in the highest yield increments, and also significantly increased the number of wheat spikes m<sup>-2</sup>, grains spike<sup>-1</sup>, grains m<sup>-2</sup>, plant height, and biomass yield, while decreasing harvest index. Thousand kernel weights and broadleaf weed seedling densities were unaffected by N rate and timing. Split application of N should be recommended as an economic risk-aversion strategy in this marginal rainfall zone.

**Key Words:** Ethiopia, fertilizer, nitrogen, *Triticum aestivum* L., wheat, yield

### RÉSUMÉ

Des essais sur le taux d'engrais et le rythme d'application de l'azote ont été menés sur le blé à pain (*Triticum aestivum* L.) dans les champs de paysans durant deux saisons annuelles de culture sur une période de trois ans dans un district enclin à la sécheresse du sud-est de l'Éthiopie. Les taux de N avait un effet bénéfique sur le rendement en grains, mais la réaction à l'N n'était économiquement acceptable que jusqu'à 41 kg ha<sup>-1</sup>, cela uniquement durant la plus fiable seconde saison de culture. Les rendements moyens de grains obtenus durant différentes saisons étaient corrélés aux totaux des précipitations saisonnières, mais la réaction à l'azote ne l'a pas été. L'application précoce de N, soit la totalité durant les semences ou l'application divisée entre la période des semences et celle du mi-labour, a produit la plus grande augmentation de rendement, et a aussi significativement augmenté le nombre d'épis de blé par mètre carré, grains par épi, grains par mètre carré, la hauteur et le rendement en biomasse, tout en réduisant l'indice de récolte. Les poids de mille grains et les densités des plants de mauvaises herbes à feuilles obtuses n'étaient pas affectés par le taux et le rythme d'application de N. L'application séparée de N devrait être recommandée comme stratégie d'économie évitant ainsi le risque dans cette zone aux précipitations marginales.

**Mots Clés:** Éthiopie, engrais, azote, *Triticum aestivum* L., blé, rendement

## INTRODUCTION

In the Sinana district of Bale Region of southeastern Ethiopia, bread wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) production dominate the peasant farming systems in the mid- to high-altitude zones (i.e., >2000 m a.s.l.) (Alemayehu and Franzel, 1987). Rainfall in this district is distributed bimodally with an annual total of approximately 850 mm, being split nearly equally between two growing seasons - the first rains ("belg") from March to June and the second rains ("meher") from July to October (Zewdu *et al.*, 1992). Erratic climatic conditions, manifested in late commencement of the "belg" rains, prolonged dry spells during the growing cycle, and/or suboptimal amounts of seasonal rainfall, are a constant threat to the farming community in this district.

The initial farming system survey in Sinana district (which preceded agricultural research) revealed that peasant farmers recognize low soil fertility as one of the major constraints to wheat production (Alemayehu and Franzel, 1987). However, Ministry of Agriculture statistics indicate that only 15% of the wheat crop in Bale Region receives inorganic fertilizer (Asnakew *et al.*, 1991). The maximum rate of application encountered during the survey was 50 kg of diammonium phosphate (DAP) ha<sup>-1</sup>, representing 9 kg N and 10 kg P ha<sup>-1</sup>. Furthermore, none of the surveyed farmers practised manuring, and crop rotation with legumes occurred infrequently.

On-farm fertilizer trials conducted on bread wheat in peasants' fields in Sinana district over four growing seasons revealed a highly significant and economic response to P applied at a rate of 20 kg P ha<sup>-1</sup>. The relatively lower biological response to N was not economic (Amanuel *et al.*, 1991).

Two explanations were postulated for the absence of an economic response to N in Sinana district. Timing of N application had previously shown a minimal effect on wheat grain yield in Arsi and Shewa Regions of Ethiopia (Asnakew, 1990), but split application was advocated to minimize the proliferation of weeds in peasants' crops (Tanner *et al.*, 1993). The on-farm trials conducted in Sinana district in 1988 and 1989 were based on split application of N: one-third of

the N was broadcast at sowing, and the remainder was broadcast at the mid-tillering stage. Conceivably, the second application may have been too late to benefit wheat grain yield under moisture-limited conditions. Other reports indicate that wheat yield response to timing of N application is highly dependent upon seasonal precipitation (Anderson, 1985; Cartee *et al.*, 1986).

Secondly, the variety used in fertilizer trials can affect the observed N response (Anderson, 1985). The semidwarf cultivar Dashen, a CIMMYT line released in Ethiopia in 1984, had been used in the previous on-farm trials because of its recognized high yield potential. However, Dashen's resistance to stripe rust (*Puccinia striiformis*) broke down dramatically in 1988, and the variety exhibited high infection levels; in fact, stripe rust incidence increased in a linear fashion with fertilizer N level (Tanner *et al.*, 1993). Thus, the measured grain yield response of bread wheat to fertilizer N could have been reduced by the effects of the foliar pathogen.

This paper presents the results of a multi-location, on-farm trial conducted in Sinana district of southeastern Ethiopia during several cropping seasons from 1990 to 1993 to examine the effects of nitrogen fertilizer rates and timing of application on an adapted, disease-resistant, and locally popular bread wheat cultivar.

## MATERIALS AND METHODS

In 1990, on-farm fertilizer trials were established at five sites in the first growing season ("belg" from March to June) and four sites in the second season ("meher" from July to October). No trials were sown in 1991 because of political insecurity in the countryside. In 1992, four trials were sown in each of the two cropping seasons, and, in 1993, three trials were sown in each season. Thus, a total of 23 trials were established over six growing seasons.

Host farmers were initially identified by local extension agents of the Ministry of Agriculture as representative wheat producers based on historic yield levels, cropping practices, and soil types. Selected farmers agreed to host an on-farm fertilizer trial on fields accessible during the rainy season. The trial fields were located between

2200 and 2500 m a.s.l., and soil textures varied from sandy loams to loamy clays. All sites were located within a radius of approximately 20 km from the Sinana Research Centre (alt. 2400 m a.s.l., latitude 7°10'N, longitude 40°5'E).

Individual trials consisted of 16 treatments in a 3 x 5 factorial arrangement of three N rates (41, 82 and 123 kg N ha<sup>-1</sup> from urea) applied at five timings: (T1) all at sowing, (T2) split 1/3 at sowing and 2/3 at tillering, (T3) split 2/3 at tillering and 1/3 at booting, (T4) all at tillering, and (T5) all at booting. A zero N plot constituted the sixteenth treatment in each replication. The treatments were arranged in a randomized complete block design with 3 replications per site. Gross plot size was 5 x 5 m.

Host farmers followed their customary and preferred practices for non-experimental factors such as cropping sequence (i.e., most farmers followed the common rotation of wheat after barley), and timing and frequency of pre-plant tillage passes with the local ox-plough.

Research staff laid out the trials, broadcasting preweighed amounts of urea on the sowing date preferred by each host farmer. Triple superphosphate (TSP) was applied at the recommended rate of 20 kg P ha<sup>-1</sup> across all treatments. Subsequent to fertilizer application, host farmers immediately broadcast seed of the adapted and disease-resistant bread wheat cultivar ET13, which had been recommended in 1989 for peasant farmers in Sinana district. The recommended seed rate of 150 kg ha<sup>-1</sup> was used, and one pass was made across the field with the local ox-plough to incorporate both seed and fertilizer.

All trials received a blanket application of a broadleaf herbicide at 3 l ha<sup>-1</sup> (BrittoxR 52.5 EC: 525 g ioxynil + bromoxynil + MCPP l<sup>-1</sup>: Rhône-Poulenc), within 20-25 days post-emergence, plus one supplementary hand weeding at 35-40 days post-emergence. Broadleaf weed seedlings were counted on a total area of 1.0 m<sup>2</sup> in each plot prior to herbicide application.

Data on plant height and spike density (i.e., spikes m<sup>-2</sup>) were collected prior to harvest. At crop maturity, a 9.0 m<sup>2</sup> area was hand-harvested at ground level from each plot, and biomass and grain yields determined. Harvest indices (HI)

were calculated for each plot, and thousand kernel weights (TKW) were determined for each grain sample. Grain number spike<sup>-1</sup> and m<sup>2</sup> were calculated for the harvest areas.

All data were subjected to analysis of variance, first considering individual trials, and then pooling the data for a combined analysis. Nitrogen responses were subjected to economic and sensitivity analysis using partial budget methodology (CIMMYT, 1988). The economic analyses utilized a field price for grain ranging from 1.1 to 1.7 Ethiopian Birr (EB) kg<sup>-1</sup>, and a price for N ranging from 2.92 EB kg<sup>-1</sup> (i.e., the current official price of N including a 16% subsidy) up to 6.78 EB kg<sup>-1</sup> (i.e., removing the subsidy and doubling the price of N).

## RESULTS

Of the total of 23 on-farm nitrogen rate by timing trials sown over six cropping seasons, ten were successfully harvested. Of the remaining 13, seven were lost due to the effects of drought (i.e., all trials in the 1992 and 1993 "belg" seasons), three were harvested prematurely by the host farmers, two were severely damaged by grazing livestock, and one was destroyed by phytophagous beetles.

The characteristics of each growing season (i.e., the ten day period or decade during which each season began, the seasonal rainfall, and the number and mean yield of trials harvested each season) are summarized in Table 1. The relatively high variation associated with the first ("belg") season is apparent for the three years of conducting trials: the commencement of the "belg" rains, in particular, and the seasonal total in 1993 varied quite markedly from the 1981-93 means (i.e., climatic data have only been available in Sinana district since 1981). In fact, farmers recognize the unreliable nature of the "belg" rains, and prefer to sow proportionately more early-maturing barley during the first season; during the second ("meher") season, wheat is the dominant crop (Alemayehu and Franzel, 1987).

The monthly mean maximum and minimum temperatures and rainfall totals for 1990 are presented in Fig. 1, clearly illustrating the bimodal nature of rainfall distribution in Sinana district. On the basis of the 1981-93 climatic data, monthly

mean maximum and minimum temperatures are slightly lower in the "meher" season, by 0.9 and 0.6 °C, respectively, relative to the "belg" season.

Although the seasonal rainfall of 368 mm in the 1992 "belg" rains was similar to the 13 year mean (Table 1), distribution was poor and many farmers' crops failed. Most of the seasonal total was received early in the cropping cycle, perhaps related to the late onset of the rains, which also delayed sowing and subjected the crop to late season drought stress. Furthermore, the relatively high rainfall recorded during the 1992 "meher" season began slightly early, and interfered with the harvest of the (late-sown) "belg" crop. This resulted in additional "belg" crop losses for some farmers, and poor land preparation for the "meher" season.

TABLE 1. Seasonal precipitation characteristics at Sinana Research Centre and wheat grain yields (kg ha<sup>-1</sup>) in Sinana district in 1990, 1992 and 1993

Characteristic	1981-93 <sup>a</sup>	1990	1992	1993
Decade <sup>b</sup> in which "belg" season began	9	6	11	10
Cumulative rainfall over 110 days (mm)	364	345	368	230
Mean yield of fertilizer trials	2297 —	N <sup>d</sup> (3/5) <sup>c</sup>	N (0/4)	(0/3)
Decade in which "meher" season began	22	23	22	23
Cumulative rainfall over 110 days (mm)	355	428	519	362
Mean yield of fertilizer trials	2184 —	2962 (2/4)	1156 (3/4)	(2/3)
Total annual rainfall (mm)	833	842	1003	734

<sup>a</sup>: Means over a 13 year period.

<sup>b</sup>: Ten day calendar period.

<sup>c</sup>: Numbers in parentheses indicate on-farm trials harvested over trials planted in a specific season.

<sup>d</sup>: All trials failed in this specific season.

**Grain yield response.** Mean grain yields of the ten on-farm nitrogen rate by timing trials ranged from 818 to 3342 kg ha<sup>-1</sup>, with associated coefficients of variation (C.V.s) ranging from 11.5 to 39.1%. Three of the ten trials exhibited significance for the effect of N rate (i.e., one trial each season except "meher" 1993), and eight trials exhibited a significant effect of N timing on grain yield (i.e., all trials except one in "belg" 1990 and one in "meher" 1992). Individual trial mean yields were correlated with seasonal rainfall totals ( $r=0.56$ ,  $P=0.091$ ) as were C.V.s ( $r=-0.58$ ,  $P=0.074$ ). However, the control treatment yields were not correlated with seasonal rainfall ( $r=0.27$ ,  $P=0.40$ ), nor was N response whether measured as the percentage increase in yield from 0 to 81 kg N ha<sup>-1</sup> applied at sowing ( $r=0.18$ ,  $P=0.63$ ), or as kg grain:kg N over the same interval ( $r=0.38$ ,  $P=0.28$ ). Since the principal objective of this study was to estimate an overall response to N rate and timing, the data were combined in a pooled analysis.

The mean grain yield for the combined analysis (excluding the failed trials) was 2246 kg ha<sup>-1</sup> with an associated C.V. of 21.1% (Table 2). This yield level is markedly higher than the mean yield of 1569 kg ha<sup>-1</sup> reported for the previous on-farm fertilizer trials in Sinana district (Amanuel *et al.*, 1991), reflecting the superior stripe rust resistance of the bread wheat cultivar, ET13, used in the current study. The interaction of both main effects (i.e., N rate and timing) with trials (i.e., ten trials harvested over four seasons) was highly significant ( $P<0.001$ ), but the main effect variances significantly exceeded the interaction variances (i.e.,  $P<0.05$  for N rate,  $P<0.001$  for time of application).

N rate had a significant ( $P<0.05$ ) positive effect on grain yield (Table 2), but the grain:nutrient response ratio was only 2.1, 3.8 and 2.0 kg grain:kg N for the three successive increments of 41 kg N ha<sup>-1</sup> applied in this study (i.e., averaged across timings). This response is comparable with the ratio of 2.2 kg grain:kg N for the interval from 0 to 41 kg N ha<sup>-1</sup> in the previous study (Amanuel *et al.*, 1991).

Time of nitrogen application exhibited a more pronounced effect on grain yield than did N rate. The highest grain yield was obtained by application of all N at sowing (T1) or split between sowing

and tillering (T2). Delaying all N application until mid-tillering or later (T3, T4 and T5) significantly reduced grain yield. Orthogonal contrasts showed that application of some or all of the N at sowing (T1 and T2) significantly ( $P < 0.001$ ) increased yield vs. no N at sowing. Applying all N at booting (T5) significantly ( $P < 0.01$ ) reduced grain yield. There was no statistical difference between the yields obtained by applying all N at sowing (T1), or splitting N between sowing and tillering (T2).

The effect of time of N application appeared to be independent of N rate as indicated by the non-significant interaction term (Table 2). However, the use of orthogonal contrasts to partition the rate by timing interaction revealed that grain yield response to N differed among the timings. T1 and T2 showed evidence of a quadratic response while T3 was linear over the range of N rates used in this study. Furthermore, the response to N was highest for the early application timings (T1 and T2):

grain yield responses were 8.5 and 7.4 kg grain: kg N over the 0 to 41 kg N interval, respectively. This suggested that the low N rate could have been economic in the present study, considering that 2.7 kg of grain suffices to recover the cash cost of 1 kg of fertilizer N.

**Yield components.** The interaction of N rate by timing was non-significant for all grain yield components measured in the present study (Table 2). Nitrogen rate had a significant increasing effect on the number of spikes  $m^{-2}$ , and, as a result, on the number of grains  $m^{-2}$ . Grains  $spike^{-1}$  and thousand kernel weights (TKW) were not increased by N application, suggesting that the effect of N under the relatively dry conditions of this study occurred early in the crop growth cycle, affecting the number of tillers produced, but not the size of spike primordia or individual seeds.

TABLE 2. The effects of N rate and application timing on grain yield and yield components (data combined across seasons and years 1990-1993)

	Grain yield (kg ha <sup>-1</sup> )	TKW (g)	Grains m <sup>-2</sup>	Spikes m <sup>-2</sup>	Grains spike <sup>-1</sup>
N rate (R):	*	NS	P<0.10	*	NS
0 (kg ha <sup>-1</sup> )	2041	33.4	6111	310	19.9
41 (kg ha <sup>-1</sup> )	2128	33.6	6333	336	18.4
82 (kg ha <sup>-1</sup> )	2283	34.3	6656	354	18.5
123 (kg ha <sup>-1</sup> )	2366	34.1	6938	368	18.4
Linear response	*	NS	*	*	NS
Quadratic response	NS	NS	NS	NS	NS
Timing (T):	***	NS	***	P<0.10	*
T1 sowing	2527	34.6	7303	371	19.5
T2 sowing/tillering <sup>a</sup>	2456	34.1	7202	367	19.2
T3 tillering/booting <sup>b</sup>	2180	34.2	6374	348	17.9
T4 tillering	2145	33.5	6403	352	17.6
T5 booting	1987	33.5	5931	326	18.1
LSD(P=0.05)	258	NS	667	27 <sup>c</sup>	1.5
R x T:	NS	NS	NS	NS	NS
Mean:	2246	33.9	6625	350	18.5

<sup>a</sup>: Split 1/3:2/3.

<sup>b</sup>: Split 2/3:1/3.

<sup>c</sup>: LSD at the 10% level of significance.

\*, \*\*\*: Significant at P=0.05 or P=0.001, respectively.

Time of N application affected both spikes  $m^{-2}$  and grains  $spike^{-1}$ , and, as a result, grains  $m^{-2}$ . Nitrogen timing did not affect TKW. Partitioning the sum of squares for timing revealed that applying all N at booting (T5) significantly reduced the number of spikes  $m^{-2}$  and grains  $m^{-2}$ . Applying some or all of the N at sowing (T1 and T2) significantly increased the number of spikes  $m^{-2}$ , grains  $spike^{-1}$ , and the number of grains  $m^{-2}$ . The remaining contrasts (i.e., all N at sowing vs. split between sowing and tillering) were not significant for any of the yield components. No contrasts were significant for TKW.

**Other crop parameters.** Plant height, biomass yield and harvest index (HI) were all significantly affected by N rate and timing (Table 3), while

TABLE 3. The effects of N rate and application timing on selected wheat crop agronomic parameters (data combined across seasons and years 1990-93)

N rate and timing	Plant height (cm)	Biomass (kg ha <sup>-1</sup> )	HI (%)
N rate (R):	**	***	**
0 (kg ha <sup>-1</sup> )	98	6926	29.4
41 (kg ha <sup>-1</sup> )	101	7590	27.7
82 (kg ha <sup>-1</sup> )	105	8605	26.6
123 (kg ha <sup>-1</sup> )	106	9322	25.4
Linear response	**	***	**
Quadratic response	NS	NS	NS
Timing (T):	***	***	***
T1 sowing	112	10254	24.6
T2 sowing/tillering <sup>a</sup>	108	9169	26.7
T3 tillering/booting <sup>b</sup>	102	8024	27.0
T4 tillering	102	8325	25.8
T5 booting	96	6755	28.6
LSD(P=0.05)	4	889	1.7
R x T:	NS	*	**
Mean:	104	8407	26.7

<sup>a</sup>: Split 1/3:2/3.

<sup>b</sup>: Split 2/3:1/3.

\*, \*\*, \*\*\*: Significant at P=0.05, P=0.01 or P=0.001, respectively.

only plant height exhibited a non-significant interaction between the two factors. The significant N rate by timing interaction effects for biomass yield and HI were due to a 63% increase in biomass yield with 81 kg N ha<sup>-1</sup> at sowing while HI decreased by 7 percentage units. With 81 kg N applied at booting, biomass yield increased by only 1.2% while HI decreased by 0.9 percentage units (i.e., both responses were non-significant).

Plant height and biomass yield responded positively and linearly to increasing N rates, while HI was reduced linearly. The response of plant height and biomass yield to N timing revealed that application of all N at booting decreased both parameters, application of all or some of the N at sowing increased both, and application of all N at sowing increased both. Harvest index increased with the delay of N application until booting (T5) because of the dramatic decrease in total biomass production. HI was decreased significantly by the application of all N at sowing due to increased biomass production.

The density of broadleaf weed seedlings (i.e., at the time of spraying herbicide) was not significantly affected by N rate or timing. The absence of an effect of basal N application on early weed density in the current study contrasts with previous results on bread wheat in high rainfall zones in Ethiopia (Tanner *et al.*, 1993).

**Economic analysis.** The technical results discussed in the previous sections indicate that the biologically advantageous timings for N application were all N at sowing (T1) or N split between sowing and tillering (T2). In fact, despite the lack of significant difference, one can argue that the latter approach is beneficial from the perspective of economic risk aversion - when crop emergence or stand establishment fail due to any combination of factors (eg., poor seed quality, insect or disease damage, or post-seeding drought), the peasant farmer can reserve at least part of the intended N application for a future cropping season.

The economic risk to the peasant farmer posed by the erratic and unreliable nature of the first rains in Sinana district was reflected in the present study. Of 12 trials planted in three "belg" seasons, seven trials in two seasons failed due to drought (Table 1). Considering that in the three "belg"

season trials successfully harvested, the N response (kg grain:kg N) was <1 for the lowest rate of N applied (41 kg ha<sup>-1</sup>) at sowing, the use of N fertilizer cannot be recommended for peasant wheat producers in Sinana district in the "belg" season.

The grain yield response to all N applied at sowing for the seven trials harvested successfully in the second ("meher") season was subjected to economic analysis following partial budget methodology (CIMMYT, 1988). The results of partial budget analysis at a grain price level of 1.1 Ethiopian Birr (EB) kg<sup>-1</sup> (Table 4) indicate that 41 kg N ha<sup>-1</sup> was profitable and exceeded the minimum acceptable rate of return (MARR) of 100% generally cited as a precondition for smallholder adoption of new agricultural technology (CIMMYT, 1988). The marginal rate of return (MRR) for 41 kg N ha<sup>-1</sup> only fell below 100% when fertilizer N price was increased to 6.78 EB kg<sup>-1</sup> of N (i.e., removing the current 16% fertilizer subsidy and doubling the price). The 41 kg N ha<sup>-1</sup> rate tolerated a price increase of 86%

produced a lower net benefit at a higher cost) across all N price levels.

Using a grain price level of 1.7 EB kg<sup>-1</sup> (i.e., roughly double the mean grain price in recent years), the 41 kg N ha<sup>-1</sup> rate tolerated N price increase of 374% relative to the current price level with the subsidy removed before the MRR fell below 100%. Thus, 41 kg N ha<sup>-1</sup> appears to be economically feasible, and should be recommended for peasant wheat producers in Sinana district during the "meher" season, taking into consideration the limited risk of crop failure in the second season.

## DISCUSSION

In the present study, using a disease resistant bread wheat cultivar, a significant and economic response to fertilizer nitrogen was found in Sinana district, particularly when N was applied all at sowing or split between sowing and tillering. Undoubtedly, the low agronomic and uneconomic response to N fertilizer reported in previous seasons in Sinana district (Amanuel *et al.*, 1991) was a consequence both of low seasonal rainfall in this zone, and of the incidence of stripe rust on the susceptible wheat cultivar used. The minimal difference in the present study between applying all N at sowing or splitting N between sowing and tillering refutes the hypothesis that split application of N may have been responsible for the reduced N response in the 1988-89 trials (Amanuel *et al.*, 1991).

Fischer *et al.* (1993) reported no decrease in the yield response of irrigated bread wheat to N until applications were delayed beyond the onset of stem elongation. Similarly, Asnakew (1990) reported a minimal effect of delaying N application on rainfed bread wheat in the central highlands of Ethiopia. However, under low seasonal rainfall in Syria, Anderson (1985) reported a differential response to timing of N application. With all N applied at sowing one variety responded positively, but with all N at tillering no variety was responsive. The latter observation agrees with the results of the present study whereby delaying all N until tillering (or later) was detrimental to grain yield.

Although delayed application of N can increase net economic returns by increasing grain protein

TABLE 4. Summary of the marginal rate of return (%) analyses of the nondominated<sup>a</sup> N treatments applied at sowing

N rate (kg ha <sup>-1</sup> )	N price (EB kg <sup>-1</sup> )				
	2.92	3.39	4.24	5.09	6.78
0					
41	331	272	197	148	86
82	154	119	75	46	10
123	D	D	D	D	D

<sup>a</sup>: Includes only nondominated treatments based on a grain price of 1.1 Ethiopian Birr (EB) kg<sup>-1</sup>. US\$1.00 = 6.27 EB on Oct. 7, 1994.

relative to the current price of N with the subsidy removed before the MRR fell below the MARR. The 82 kg N ha<sup>-1</sup> rate had an associated MRR of only 75% (relative to 41 kg N ha<sup>-1</sup>) when the N price was increased by 25% relative to the current unsubsidized N price level. The 123 kg N ha<sup>-1</sup> rate was dominated by 82 kg N ha<sup>-1</sup> (i.e., 123 N

content (Cartee *et al.*, 1986), this aspect is not relevant in Bale Region of Ethiopia where grain yield is the sole determinant of economic benefit to the farmer (i.e., in Bale there is no premium for grain protein content). Nonetheless, protein enhancement via split or delayed application of N could be beneficial for the peasant sector. In those regions of Ethiopia where wheat is a basic staple its contribution to total dietary protein intake ranges from 32 to 78% (Aberra, 1991).

Furthermore, split application of N fertilizer has positive implications for N use efficiency. Under irrigated or high rainfall conditions, N use efficiency (i.e., N recovery by the crop) is usually improved by minimizing the basal application (Lutcher and Mahler, 1985). Although split application of N in the present study did not reduce the early emergence of broad leaf weed seedlings, as reported in higher rainfall zones in Ethiopia (Tanner *et al.*, 1993), split application should be recommended as an economic risk-aversion strategy for peasant farmers in this marginal rainfall zone. In case of crop failure in the early post-emergence period, farmers can avoid complete loss of the fertilizer input.

Although N fertilizer, particularly with early application, increased wheat grain yield significantly, the response to N was economically acceptable for peasant farmers in Sinana district only up to the rate of 41 kg N ha<sup>-1</sup>, and then only during the second ("meher") season.

One aspect intentionally omitted from the present economic analysis was the potential value of the straw produced in response to fertilizer N. Unlike wheat producing regions in central Ethiopia, Sinana district, in common with most of Bale Region, does not have a developed market for wheat straw as livestock feed. Should such commercialization occur in the future, the economic response to N fertilizer will increase greatly. For example, the incremental straw response to 41 kg N ha<sup>-1</sup> applied at sowing was 43.7 kg straw:kg N. In areas of Ethiopia where straw is marketed, the farm-gate value of wheat straw is about 16% of the monetary value per kg relative to wheat grain (Tanner and Mwangi, 1992). Thus, the 43.7 kg straw response would add a value equivalent to an additional 7.0 kg grain:kg N. The opportunity cost associated with commercialization of straw is that less crop residue

would be returned to the soil, leading eventually to a decline in soil organic matter (Wall and Causarano, 1994).

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