Vol. 7(4), pp. 60-66, June 2021
DOI: 10.5897/JODA2020.0047
Article Number: 9BEDF5866997
ISSN 2476-8650

http://www.academicjournals.org/JODA

Journal of Dryland Agriculture

Full Length Research Paper

Agronomic and economic evaluation of nitrogen fertilizers types and levels on bread wheat (*Triticum Aestivum L.)* in the *vertisols* of northern highlands of Ethiopia

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Received 28 May, 2020; Accepted 8 September, 2020

Optimum nitrogen fertilization from the right source is the most important production factors for higher grain yield of wheat. Study to investigate the effect of type and rate of Nitrogen fertilizer on yield of bread Wheat was conducted in Ofla and Endamehoni districts of northern Ethiopia in 2017 and 2018 main cropping season. The treatments consists four levels of different sources of nitrogen fertilizer (Prilled urea, granular urea, urea super granule and UREAstabil) each with three application rates (46, 69 and 92 kg N ha^{-1}) and one control (without any N fertilizer application) laid down in a randomized complete block design replicated three times. Grain yield of was affected significantly to the application rates and source of nitrogen fertilizer at Adigolo and Mekan districts of Ofla and Endamehoni respectively. The highest grain yield of 5.11 and 4.08 tha^{-1} was obtained from application 92 and 69 kg N ha^{-1} of UREAstabil at Adigolo and Mekan districts respectively. In both Adigolo and Mekan districts, grain yield of wheat showed that a linear increase with increasing rate of N fertilize while, application of 46 kg N ha^{-1} from UREAstabil reaches optimum agronomicaly and economically for the study areas.

Key words: Prilled urea, super granular urea, granular urea, UREAstabil.

INTRODUCTION

Wheat is one of the most important cereals cultivated in Ethiopia. In area of production, wheat ranks 4th after Teff, maize and sorghum and 3rd in total grain production after maize and teff and 2nd in yield to maize. More than 4.22 million farmers cultivate it (CSA, 2017). However, the mean national yield is 2.7-ton ha^{-1} which is below the world's average of 3.4 t ha^{-1} (FAOSTAT, 2014). The low yield of wheat in Ethiopia is primarily due to depleted soil fertility (Asnakew et al., 1991) little or no addition of fertilizers (Asnakew et al., 1991; Amsal et al., 1997), unavailability of other modern crop management inputs (Asnakew et al., 1991), soil degradation (Stahl, 1990), poor rainfall distribution and wheat diseases (ICARDA, 2013). Therefore managing soil fertility is crucial for improving agricultural productivity in Ethiopia. Nevertheless, many farmers refrain from using fertilizer

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due to escalating costs (Kefyalew, 2010), uncertainty about the economic returns to fertilizing food crops and, more often, lack of knowledge as to which kinds and rates of fertilizers are suitable (Hopkins et al., 2008). The physical application rates of fertilizer are also well-below those recommended and estimated. Only 30 to 40% of Ethiopian smallholders use fertilizer (Spielman et al., 2012) and the physical application rates of fertilizer are on average only 37 to 40 kg ha^{-1}.

Nitrogen is the most limiting factor calling for external inputs in the form of fertilizer for profitable cereal crop production in most agro-ecological zones. However, conventional N fertilizers are highly soluble and, once applied to the soil may be lost from the soil plant system or made unavailable to the plants through the processes of leaching, NH_3 volatilization, denitrification and immobilization and fixed in the soil solids as NH4-N form (Bock, 1984) particularly on soils that have a relatively high pH. High pH content of the vertisols favors gaseous loss of ammonia when urea or ammonium fertilizers are applied to the surface (Terman, 1979). On the other hand, the low infiltration rates of vertisols could also create environment favorable for denitrification since O_2 diffusion rate in water is very low (Russel, 1977). The N recovery by crops from the soluble N fertilizers such as urea is often as low as 30 to 40%, with a potentially high environmental cost associated with N losses via NH_3 volatilization, NO_3- leaching and N_2O emission to the atmosphere (Zhou et al., 2003).

In order to improve urea-N recovery and reduce its loss, many forms of slow-release urea fertilizers have been developed and applied to different plant species under a range of environmental conditions. Application of urea stable (have long release, up to 60 days, and have high N use efficiency) can also lower losses of nitrogen. The products may be coated, chemically and biochemically modified, or are granular (Jiao, 2005).

Such slow-release urea fertilizers can increase the efficiency of applied urea-N and can avoid negative environmental effects because their N release is in synchrony with plant N uptake, and in a single application, can provide sufficient N to satisfy plant N requirements while maintaining very low concentrations of mineral N in soil throughout the growing season (Bacon, 1995). Therefore evaluating these sources of nitrogen fertilizer on wheat is of paramount important.

MATERIALS AND METHODS

Description of experimental sites

This study was conducted in 2017 and 2018 main cropping season at Ofla (Adigolo) and Endamehoni (Mekan) districts of south Tigray, northern Ethiopia. The study districts receives a bimodal rainfall pattern with the main wet season (‘Kiremt’) extending from July to September and the small wet season (‘*Belg*’) which extends from March to May. The areas are characterized by heavy and erratic rainfall distribution. Adigolo is located on the geographic coordinates of 12°31’15", 39°30'4 and lies at an altitude of 2435 m.a.s.l. The long-term (1997-2018) mean annual rainfall was 726.3 mm, while the mean annual rainfall for the study period of 2017 and 2018 was 806.5 and 1070 mm, respectively. Similarly, the mean maximum and minimum monthly temperatures were 22.3 and 7.8°C, respectively. Mekan is located on the geographic coordinates of 12°44'31”, 39°31'17" and lies at an altitude of 2450 m.a.s.l. (Figure 1). The long-term (1999-2018) mean annual rainfall was 685.4 mm with the mean annual, rainfall for the study period of 2017 and 2018 was 477.8 and 838.7 mm respectively with the mean maximum and minimum monthly temperatures were 22.4 and 10.2°C, respectively (Figure 2).

Mono cropping of cereals, mainly bread wheat (*Triticum Aestivum L.*), Barley (*Hordium Vulgare L.*) and pulses is a common practice in these areas. Wheat is the predominant staple food crop for the rural population in these districts.

Experimental materials, procedures and design

The field experiment consists four different source of nitrogen fertilizer (Prilled /Conventional urea, granular urea, urea super granule and UREAstabil) each with three application rates (46, 69 and 92 kg N ha^{-1}), and one control (without any N fertilizer application). The field experiment was laid down in a randomized complete block design with three replications. All experimental unites were treated with a uniform rate of 46 kg P_2O_5 ha^{-1} in the form of triple super phosphate (TSP), 60 kg K_2O ha^{-1} from muriate of potash (KCl) and 5 kg S ha^{-1} from $CaSO_4$ at sowing time. Nitrogen fertilizer was applied in two splits, 1/3rd at sowing and 2/3rd after 40 days of sowing. The plot size was 2 m × 3 m (6 m^2) gross size and 1.6 m × 3 m (4.8 m^2) net size and there were 10 rows in each plot. The middle eight rows were used for agronomic data collection and the two rows served as border. The spacing between plants, rows, plots, and blocks were 5, 20, 50 and 150 cm, respectively. An improved bread wheat variety known kingbird was sown by drilling in rows using manual row maker at recommended seed rate of 150 kg ha^{-1} and row spacing of 20 cm and was used as test crop. Plots were kept free of weeds by hand weeding. No insecticide or fungicide was applied since there was no outbreak of insects or diseases. Harvesting was done manually using hand sickle.

Data collection

Grain yield

Grain yield (kg/plot) was taken from each plots by excluding the border rows and adjusting to 12.5% moisture level and then converted to hectare basis.

Soil sampling, sample preparation and analysis

Composite surface soil samples were collected using standard Auger from five spots from each experimental block (0-20 cm depth) to form one composite soil sample per block for initial soil fertility evaluation of the experimental fields.

Data analysis

After verifying the homogeneity of error variances, the Analysis of Variance (ANOVA) for the studied grain yield variable was computed using the GLM procedure of SAS software version 9.4 (SAS, 2015) following the standard procedures of ANOVA for RCB design (Gomez and Gomez, 1984). The differences in fertilizers rates and types were considered significant if the p-values were ≤

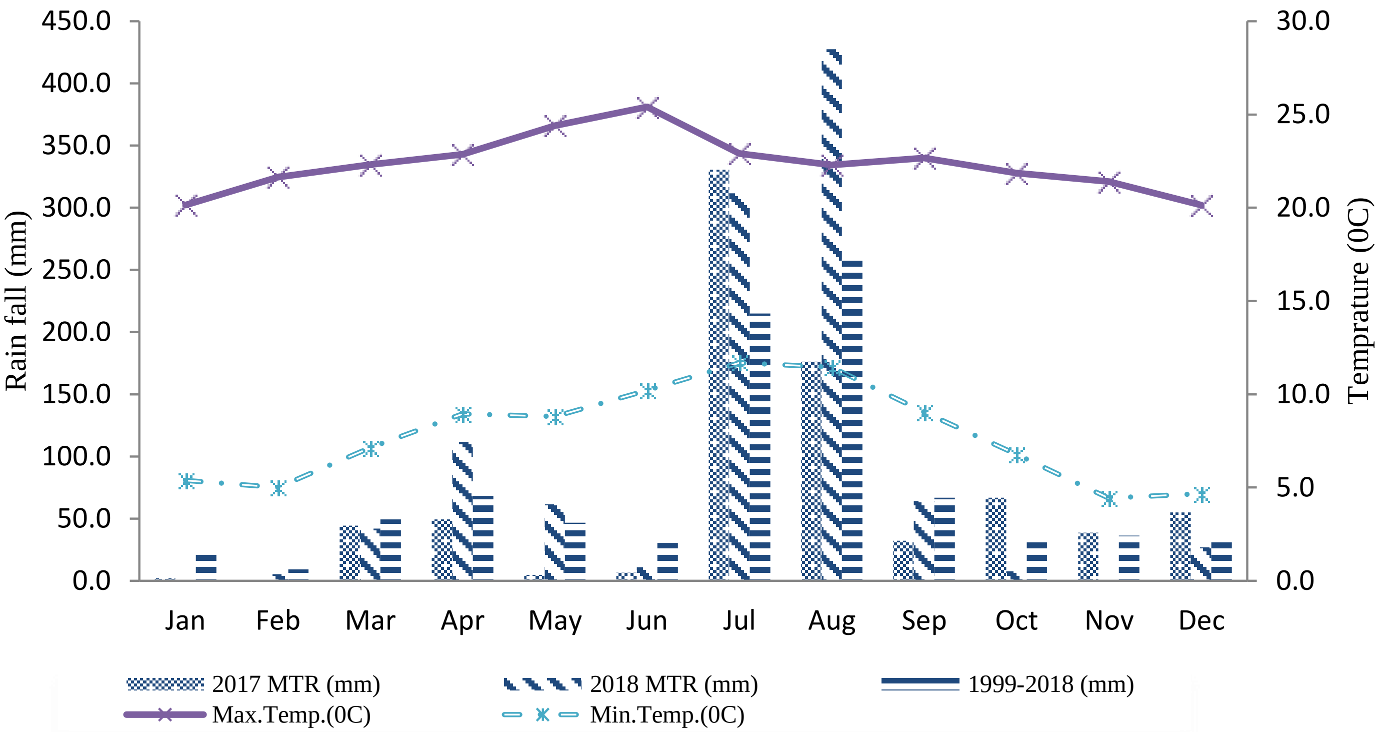

Figure 1. Monthly total rainfall (MTR), monthly maximum temperature (Max.Temp) and monthly minimum temperature (Min Temp) for 2017 and 2018 cropping season and long-term (1999-2018) average monthly rainfall of Adigolo district of Ofla.

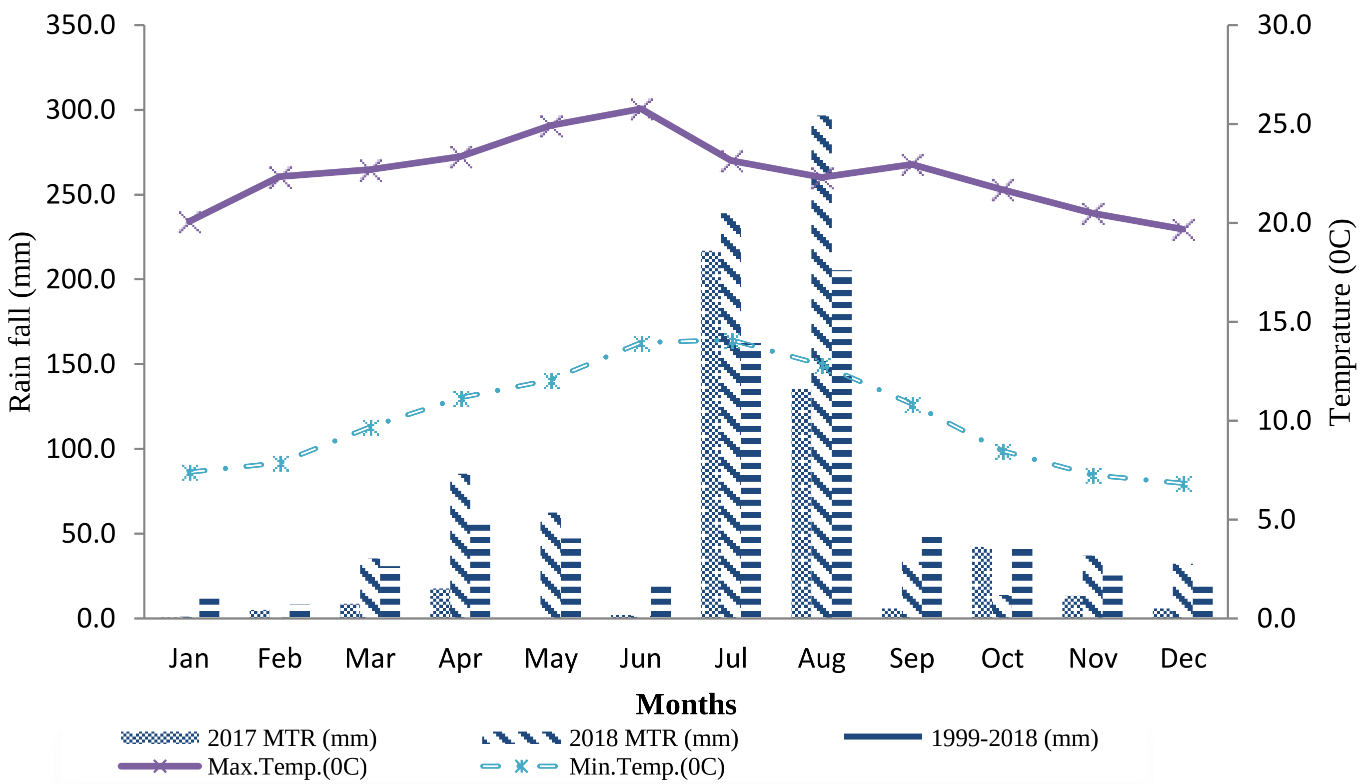

Figure 2. Monthly total rainfall (MTR), monthly maximum temperature (Max.Temp) and monthly minimum temperature (Min Temp) for 2017 and 2018 cropping season and long-term (1999-2018) average monthly rainfall of Mekan district of Endamehoni

Table 1. Soil physico-chemical properties of the study sites.

Soil properties	Ofla (Adigolo)	Endamehoni (Mekan)
pH(1:2.5 H_2O)	6.74	6.87
Available phosphorus(mg P_2O_5/kg soil)	11.00	35.10
Total nitrogen (%)	0.101	0.15
Soil organic matter (%)	1.99	1.24
Electrical conductivity (EC) (ds/m)	0.08	0.099
Cation exchange capacity(CEC) (meq/100g of soil)	41.67	48.85
Exchangeable k (meq k^+/100g of soil)	0.20	0.55
Exchangeable Na (meq Na^+/100g of soil)	0.66	0.96
Exchangeable Ca (meq Ca^{+2}/100g of soil)	25.56	24.17
Exchangeable Mg (meq Mg^{+2}/100g of soil)	8.52	8.90
Silt (%)	15	14.84
Sand (%)	25	30.05
Clay (%)	40	55.11
Textural class	clay	Clay

Source: Amanuel et al. (2015)

0.05. Least significance difference test (LSD) was used to compare among treatments at 5% probability level.

Economic data analysis

Grain and biomass yield data's for the nitrogen fertilizer effect were subjected to economic analysis, using the CIMMYT (1988) partial budget techniques to evaluate the economic profitability of nitrogen fertilizer options for determination of the economic optimum rate and type. Wheat yield was adjusted downwards by 10% to more closely approximate yields. Nitrogen fertilizer (N) rates were analyzed separately by calculating gross benefit, total costs that vary, net benefit, and the marginal rate of return for each treatment (relative to the next lowest cost or non-dominated treatment). Marginal rate of return was calculated as the change in net benefit divided by the change in total variable cost of the successive net revenue and total variable cost levels (CIMMYT, 1988). Daily labor costs for fertilizer application were calculated by assuming 150 ETB (1 US$ = 34.16 Ethiopian Birr (ETB)) person^{-1} day^{-1} and revenue was calculated by considering the prevailing market price. Dominance analysis was used to screen treatments that have higher variable cost and lower net return and dominated treatment removed from further consideration.

RESULTS AND DISCUSSION

Soil physico chemical properties of the study districts

Selected soil physico-chemical properties of the experimental sites were analyzed for composite surface soil (0-20 cm) samples collected from each replication before planting. The results indicated that texture of the soil in the Adigolo (sand 25%, silt 15% and clay 40%) and Mekan (sand 15%, silt 30% and clay 55%) experimental sites are dominated by clay (Table 1).

According to the soil pH rating developed by Tekalign et al. (1991), the mean pH values of the composite surface soil samples of the experimental sites falls under the slightly neutral soil reaction class. The soil organic matter contents were in the range of 1.24 and 1.99% at Adigolo and Mekan areas respectively thus, these values fall under low to moderate range (Tekalign et al., 1991). Total nitrogen levels of the study sites ranges between 0.101 and 0.15% at Adigolo and Mekan areas, respectively, which taken as low while those below 0.1% are very low. It, therefore soils of the Adigolo and Mekan are low to very low in their total nitrogen status. Moreover, the available phosphorus contents of the soil of the experimental site fall under the medium for Adigolo and high for Mekan and phosphorus status (Olsen et al., 1954). This indicate the low level of fertility status of the soil aggravated by long term cereal based cultivation, lack of incorporation of organic materials in to the soils through mulching or crop residues retention after harvest and frequent tillage. Continuous mono cropping and inadequate replacement of nutrients removed in harvested materials or lose through erosion and leaching. The electrical conductivity (EC) ranged from 0.08 to 0.099 dSm−1 for Adigolo and Mekan areas respectively indicating that these soils have a low content of soluble salts and that there is no danger of salinity in the study areas (Tekalign et al., 1991).

Effect of nitrogen fertilizer rate and source on grain yield

Grain yield of bread wheat showed significantly ($P < 0.05$) to the application of different rates and source of nitrogen fertilizer at Adigolo and Mekan districts of Ofla and Endamehoni Woredas respectively (Table 2).

At Adigolo district of Ofla Woreda, significantly highest mean wheat grain yield (5.11 t ha^{-1}) was obtained from

Table 2. Effect of nitrogen fertilizer rate and source on grain yield of bread wheat.

Nitrogen source (urea type)	Nitrogen rate (kg N ha^{-1})	Grain yield (ton ha^{-1}) Adigolo	Grain yield (ton ha^{-1}) Mekan	Mean grain yield (ton ha^{-1})
0	0	2.01	1.88	1.95
Prilled urea	46	3.48	2.95	3.22
Prilled urea	69	4.07	3.59	3.83
Prilled urea	92	4.56	3.99	4.28
Granular urea	46	3.30	2.78	2.78
Granular urea	69	3.74	3.20	3.47
Granular urea	92	4.68	4.10	4.39
Urea super granule	46	2.68	2.17	2.43
Urea super granule	69	3.35	2.77	3.06
Urea super granule	92	3.66	3.15	3.41
UREAstabil	46	4.15	3.66	3.91
UREAstabil	69	5.08	4.80	4.94
UREAstabil	92	5.11	4.44	4.78
LSD (5%)		0.34	0.28	0.33
SEM		0.12	0.09	0.11
CV (%)		5.30	5.00	5.60

LSD: Least significant Difference; SE: Standard error; CV: Coefficient of variation.

application of 92 kg N ha^{-1} of UREAstabil. However there were not statistically significant difference ($P > 0.05$) compared to the grain yields obtained from the application of 69 kg N ha^{-1} of UREAstabil (5.08 t ha^{-1}), 92 kg N ha^{-1} of prilled urea (4.56 t ha^{-1}) and 92 kg N ha^{-1} of granular urea (4.68 t ha^{-1}) respectively. The next highest mean wheat grain yield of 4.15 t ha^{-1} was obtained from application of 46 kg N ha^{-1} using UREAstabil which was no statistically significant difference ($P > 0.05$) with the grain yield obtained at 69 kg N ha^{-1} of prilled urea 69 kg N ha^{-1} of granular urea and 92 kg N ha^{-1} of urea supper granule. While the least wheat grain yield (2.01 t ha^{-1}) was obtained from the control plot. In agreement to this study research, findings at Hawzien indicated that the highest grain yield and highest profit was reported from application of 64 kg N ha^{-1} in the form of UREAstabil (Sofonyas et al., 2018).

At Mekan districts of Endamehoni the highest mean wheat grain yield (4.08 t ha^{-1}) was obtained from application 69 kg N ha^{-1} of UREAstabil with no statistically significant difference ($P > 0.05$) compared to the grain yield obtained from the application of 92 kg ha^{-1} of UREAstabil (4.44 t ha^{-1}). The next highest mean wheat grain yield (4.11 t ha^{-1}) was obtained from 92 kg N ha^{-1} granular urea with no statistically significant difference ($P > 0.05$) compared to the grain yield obtained from the application of 46 kg N ha^{-1} of prilled urea (3.66 t ha^{-1}), 92 kg N ha^{-1} of prillled urea (3.99 t ha^{-1}) while the least wheat grain yield 1.88 t ha^{-1} was obtained from the control plot (0). Many other research findings also reported that linear responses of grain yield to increasing rates of nitrogen fertilizer (Geleto et al., 1996).

Generally in both Adigolo and Mekan districts grain yield of wheat showed that a linear increase with increasing rate of application of N fertilizer and the grain yield of wheat obtained from all the level of UREAstabil were higher than corresponding levels of either prilled urea, granular urea or urea super granule. The application of nitrogen fertilizer increased grain yield of the bread wheat as compared to the control in both testing locations and all nitrogen types. The increase in grain yield with increasing nitrogen fertilizer rates up to adequate rate could be because of to the role of nitrogen fertilizer in increasing the leaf area and promote photosynthesis efficiency that promote dry matter production and increase grain yield. In agreement with this, Sticksel et al. (2000) reported improvements in wheat yield and its components under the acceptable increasing N rates.

Slow-release fertilizers could potentially sustain nitrogen availability during the grain-filling period.

Partial budget analysis

Partial budget analysis was computed for the nitrogen fertilizer rate and conventional plots (Tables 3 and 4). In economic analysis, it is assumed that farmers require a minimal rate of return of 100% (CIMMYT, 1988), representing an increase in net return of at least 1 Birr for every 1 Birr invested, to be sufficiently motivated to adopt a new agricultural technology. The partial budget analysis for nitrogen fertilizer rate and type showed that applying 69 kg N ha^{-1} from UREAstabil had the highest net benefits (107076.9 and 110013.8 ETB ha^{-1}) and MRR of

Table 3. Partial budget analyses of nitrogen rate and sources at Adigolo district.

Nitrogen rate (kg ha^{-1}) and source	GY.adj (t ha^{-1})	TVC (Birr ha^{-1})	GBGY (Birr ha^{-1})	BY (t ha^{-1})	GBBY (Birr ha^{-1})	TR (Birr ha^{-1})	NB (Birr ha^{-1})	MRR-ratio
0 (control)	1.81	0.00	39906.36	4.64	3618.00	43524.36	43524.36	-
46 (Prilled urea)	3.13	1800.00	69091.61	8.03	6264.00	75355.61	73555.61	16.68
46 (Granular)	2.97	1880.00	65517.90	7.62	5940.00	71457.90	69577.90	D
46 (Urea supper granular)	2.41	1910.00	53208.48	6.18	4824.00	58032.48	56122.48	D
46 (UREAstabil)	3.74	1950.00	82393.73	9.58	7470.00	89863.73	87913.73	794.78
69 (Prilled urea)	3.66	2700.00	80805.41	9.39	7326.00	88131.41	85431.41	D
69 (Granular)	3.37	2820.00	74253.62	8.63	6732.00	80985.62	78165.62	D
69 (Urea supper granular)	3.02	2865.00	66510.60	7.73	6030.00	72540.60	69675.60	D
69 (UREAstabil)	4.57	2925.00	100857.90	11.72	9144.00	110001.90	107076.90	623.35
92 (Prilled urea)	4.10	3600.00	90553.68	10.53	8209.80	98763.48	95163.48	D
92 (Granular)	4.21	3760.00	92916.30	10.80	8424.00	101340.30	97580.30	15.11
92 (Urea supper granular)	3.29	3820.00	72665.31	8.45	6588.00	79253.31	75433.31	D
92 (UREAstabil)	4.60	3900.00	101453.50	11.79	9198.00	110651.50	106751.50	391.48

GY.adj: Adjusted grain yield; TVC: Total variable cost; BY: biomass yield; GBGY: Gross benefit from grain yield; GBBY: Gross benefit from biomass yield; GB: gross benefit; NB: net benefit; D: Dominated treatment and MRR: marginal rate of return.

Table 4. Partial budget analysis of nitrogen rate and sources at Mekan district.

Nitrogen rate (kg ha^{-1}) and source	GY.adj (t ha^{-1})	TVC (Birr ha^{-1})	GBGY (Birr ha^{-1})	BY (t ha^{-1})	GBBY (Birr ha^{-1})	GB (Birr ha^{-1})	NB (Birr ha^{-1})	MRR-ratio
0 (control)	1.69	0.0	37325.35	4.34	3384.00	40709.35	40709.35	-
46 (Prilled urea)	2.65	1800.0	58469.76	6.80	5301.00	63770.76	61970.76	11.81
46 (Granular)	2.50	1880.0	55174.02	6.41	5002.20	60176.22	58296.22	D
46 (Urea supper granular)	1.96	1910.0	43162.40	5.02	3913.20	47075.60	45165.60	D
46 (UREAstabil)	3.29	1950.0	72665.31	8.45	6588.00	79253.31	77303.31	803.44
69 (Prilled urea)	3.23	2700.0	71354.95	8.29	6469.20	77824.15	75124.15	D
69 (Granular)	2.88	2820.0	63532.51	7.38	5760.00	69292.51	66472.51	D
69 (Urea supper granular)	2.49	2865.0	54915.92	6.38	4978.80	59894.72	57029.72	D
69 (UREAstabil)	4.32	2925.0	95298.77	11.08	8640.00	103938.80	101013.80	733.07
92 (Prilled urea)	3.59	3600.0	79217.10	9.21	7182.00	86399.10	82799.10	D
92 (Granular)	3.70	3760.0	81540.01	9.48	7392.60	88932.61	85172.61	14.83
92 (Urea supper granular)	2.83	3820.0	62480.25	7.26	5664.60	68144.85	64324.85	D
92 (UREAstabil)	4.00	3900.0	88151.36	10.25	7992.00	96143.36	92243.36	348.98

GY.adj: Adjusted grain yield; TVC: Total variable cost; BY: biomass yield; GBGY: Gross benefit from grain yield; GBBY: Gross benefit from biomass yield; GB: gross benefit; NB: net benefit, D: Dominated treatment and MRR: marginal rate of return.

(623.35 and 733.07) followed by 92 kg N ha^{-1} with net benefit of (106751.50 ETB ha^{-1} and 92243.36) and MRR of (391.48 and 348.98) respectively for Adigolo and Mekan districts (Table 3 and 4).

The highest marginal rates of return (794.78 and 803.44) were obtained from applications of 46 kg ha^{-1} UREAstabil in Adigolo and Mekan areas, respectively. Thus, the treatment that was non-dominated and having a marginal rate of return (MRR) greater or equal to 50% with the highest net benefit was taken to be economically profitable. Sensitivity analysis was done based on data used in the MRR analysis and with treatment results above 100% minimum rate of return, except for the control. The if-analysis was done with the assumption of an average of 30% rises in all variable costs within 3 years, keeping the prices of the produce constant. The analysis showed that the recommended rate of 46 kg N ha^{-1} UREAstabil still hold positive benefit cost ratios.

CONCLUSION AND RECOMMENDATION

Several factors limiting crop yields have been reported by many workers and the current study showed that application of different fertilizer type and rate were significantly ($P \leq 0.05$) influenced grain yield at Adigolo and Mekan districts of Ofla and Endamehoni Woredas. Significantly higher grain yields with higher net benefit were obtained from application of 69 UREAstabil both at Adigolo and Mekan districts. However application of 46 kg N ha^{-1} UREAstabil have sound and promising impact yield of bread wheat production and the determined nitrogen fertilizer type and level reaches argonomically and economically optimum for bread wheat production. Hence, slow-release nitrogen fertilizers are fertilizers designed to slowly release nutrients, which can be used to maximize nitrogen use efficiency and grain yield of crops, thus providing an economic benefit for growers in the study site and other wheat growing agro ecological zones.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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