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Sensor based validation of nitrogen fertilizer for quality protein maize variety using a handheld normalized difference vegetative index sensor at Bako, Western Ethiopia

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Regardless of the huge yield potential and area under maize production, its current productivity in Ethiopia is by far below its potential. Declining of soil fertility and poor nutrient management is among the major factors limiting the productivity of the crop. As a result, an experiment was conducted at Bako, Ethiopia in 2016 to validate the N application and determine the best rate for side dressing using handheld Normalized Difference Vegetative Index (NDVI) sensor. The experiment was laid out in randomized complete block design in factorial arrangement with three replications. Three N levels (0, 25 and 50 kg N ha^{-1}) all applied at the time planting and four N rates (19, 38, 56 and 75 kg N ha^{-1}) for side dressing. Significant differences were observed between the applied N fertilizer for grain yield and yield components. Higher correlation coefficients (0.78) between grain yield, NDIV and INSEY at V_4 were observed. Application of 25 kg N ha^{-1} and 38 kg N ha^{-1} at planting and side dressing at 35 days after sowing correspondingly, gave higher grain yield for quality protein maize in the area. Further studies are required across various locations using different maize varieties to provide conclusive recommendations.

Key words: INSEY, maize, NDVI, nitrogen.

INTRODUCTION

Maize (*Zea mays* L.) is one of the main valuable crops worldwide because of its high value as stable food and as feed for animals and even for construction purposes (Zerihun et al., 2016). Ethiopia is the fourth largest producing country in Africa, and first in the East Africa region (FAO, 2012). Maize is leading all other cereal crops in terms of production and productivity, and second in area coverage next to teff. The total land areas of 10,219,443.46 ha (81%) was under cereals of which maize covered about 17% (2,135,572 ha) and 27% (78,471,746.57 quintals) grain yields (CSA, 2017). Despite the huge area under maize production, its current

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national average yield is about 3.7 t ha^{-1} (CSA, 2017) as compared to the world's average yield which is about 5.2 t ha^{-1} (FAOSTAT, 2012). Although several factors can contribute to big yield gaps, declining soil fertility and poor nutrient management are among the major factors contributing to low productivity of maize (Mourice et al., 2015; Chimdi et al., 2012; Vesterager et al., 2008).

Nitrogen (N) management in maize cultivation system is one of the major concerns since N is an essential plant nutrient and it is the most yield limiting factor in major hybrid maize production (Baral and Abhikari, 2015; Blumenthal et al., 2008). Many farmers refrain from applying sufficient amount of fertilizer due to its prohibitive prices, or lack of knowledge of which type and rates to apply (Hopkins et al., 2008). Conversely, excessive application is uneconomical, environmentally unsafe and potentially harmful to the crop (Guo et al., 2010). About 30 to 70% of the applied N may be lost as ammonia within 7 to 10 days after application and may lead to an elevated level of NO_3 in the soil and makes it susceptible to NO_3 loss through leaching, volatilization or surface soil (Canfield et al., 2010; Xue et al., 2010a). Since yield is likely to be low under N stress during tasselling and silking, coincidence of N availability in the soil solution and plant uptake are crucial to unlocking the potential of modern hybrids.

Maize breeders have been developed and released quality protein maize (QPM) hybrids. Thus, in addition to releasing QPM varieties, it would be very crucial to have site specific nutrient managements for the benefit of farmers in terms of nutrition, economy and reduced environmental hazards; it aims at "doing the right thing, at the right place and at the right time". When used in combination with information technologies it defines precision agriculture (Bongiovanni and Deboer, 2004). Precision agriculture is mainly used in large-scale commercial farmers using satellite and sensor-based technologies, which is not affordable by African smallholder farmers. Nevertheless, in the early 2000s, Trimble Company started manufacturing a hand-held Normalized Difference Vegetative Index (NDVI) sensor, a real pace towards popularizing precision agriculture regardless of farm-scale (Trimble, 2012). NDVI correlates with many variables such as crop N deficiency, final grain yield, weed species, and long-term water stress. Lukina et al. (2001) indicated that there is a high correlation (0.80 to 0.97) between percent vegetation cover and NDVI measurements. N use efficiency could be increased by the use of spectral radiance (Ngie et al., 2014; Li et al., 2009). Hence, the use of NDVI sensor brings precision agriculture to Ethiopian smallholder farmers, increasing yield and returns of N fertilizer, as well as minimizing the risk of ecological contamination. Farmers in the utmost part of Ethiopian often do not apply adequate amounts of N fertilizer as required by the crop. They only use basal application of N mostly once in a blanket recommendation, which causes loss of N and reduces yield. Moreover, much of the effort in making fertilizer recommendation with modern approach has not been investigated, yet there is the potential of using NDVI sensors to upturn economic and environmental wellbeing in the study area rather than blanket recommendation used as national level. Lately, there was an attempt in Western and rift valley parts of Ethiopia, on in-season N fertilizer calibration using handheld NDVI sensor (Tolera et al., 2015, 2014; Addis et al., 2015), which will be used by validating the results for maize production. Thus, the objective was to validate the calibrated N rates, and determine the optimum N rate for side dressing supported by handheld NDVI sensor for quality protein maize variety.

NDVI, land cover is one of the most important data used to demonstrate the effects of land use changes, especially human activities. Some studies have produced land cover maps of the controlled classification technique over Landsat satellite imagery. In addition, agriculture planning has many benefits in terms of the environment. For instance, it is used in making decisions about the future situation of agriculture land, and it is necessary to predict how the land has changed over time and the effects of natural factors and human activities on the land. Some of the studies show that weed invasion is a problem for the agricultural ecosystems in terms of production. It causes water stress, affects light and nutrients. Many studies represent that water stress is a problem for production as well as light. Moreover, many studies recently showed that weed is to be managed with feed management (Cetin et al., 2019; Kaya et al., 2019; Cetin, 2013).

MATERIALS AND METHODS

The experiment was conducted at Bako Agricultural Research Center in 2016 cropping season. Bako lies at an altitude of 1650 m.a.s.l and is situated at 9 E 6' N latitude and 37 E 09' E longitude. The area's mean annual rainfall is 1239 mm, with unimodal distribution and maximum precipitation being received in the months of May to August (MBARC, 2014). The experimental area is characterized by warm and humid climate with mean minimum and mean maximum air temperatures of 13.5 and 29.7, respectively (WWW.IQQO.ORG). The soil type is reddish-brown clay loam Nitosols (Mesfin, 1998). It is an acidic soil with a pH range of 4.5-5.6. The farming system of the surrounding area is a mixed farming and is one of the major maize (*Zea mays* L.) growing belts in the country; *teff* (*Eragrostis tef*), finger millet, sorghum and soybean are commonly cultivated there.

The experiment was laid out in a randomized complete block design with factorial arrangement in three replications. The plot size was 5.1 x 4.5 m. The treatments consisted of three N levels (0, 25, and 50 kg N ha^{-1}) applied at the time of planting, and four N rates (19, 38, 56 and 75 kg N ha^{-1}) for side dressing applied 35 days after planting, constituting a total of 12 treatments.

The experimental fields were plowed three times at different time intervals starting from end of April and leveled manually prior to field layout. Recommended phosphorus (20 kg P ha^{-1}) in the form of triple super phosphate was uniformly and equally applied to all experimental plots at the time of planting. N fertilizer in the form of Urea was applied at different rates as constituted in the treatments.

Table 1. Analysis of variance for yield and yield traits as influenced by nitrogen rates, and interaction effects at Bako, western Ethiopia.

Source of variation	F probability (p = 0.05)							
	D.f.	PH	LA	LAI	GY	DB	HI	TKW
Nitrogen at planting (N)	2	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Nitrogen for side dressing (SD)	3	0.158	<.001	0.007	<.001	<.001	0.006	0.016
N * SD	6	0.466	<.001	0.008	<.001	0.039	<.001	0.015
Replication	2	0.002	0.293	0.529	<.001	<.001	<.001	0.072
Residual	22	–	–	–	–	–	–	–
Total	35							

d.f. = degree freedom, PH = Plant height, LA = Leaf area, LAI = Leaf area index , GY= Grain yield, DB= Above ground dry biomass, HI = Harvest Index and TKW = thousand kernel weight.

One medium maturing quality protein maize hybrid (BHQPY545) variety was used for the experiment. The variety was released by Bako National Maize Research Center in 2008. The cultivar is well adapted to altitude areas of 1000-1800 m.a.s.l and it requires an annual rainfall of 500-1000 mm with uniform distribution in its growing periods. Its yield potential ranges from 8.0-9.5 t ha^{-1} at research field and 5.5-6.5t ha^{-1} at farmers' field (Adefris et al., 2015). The trial was planted with inter-row of 75 cm and intra-row spacing of 30 cm. All other non-treatment management practices were applied as per recommendation for the variety to all experimental plots.

NDVI values were recorded from the central four rows using hand-held Green Seeker sensor at vegetative growth stage of leaf four (V4) and six (V6) of maize. The value of NDVI readings range from 0.00 to 0.99; higher reading leads to healthier plant, healthier crop canopy with a higher NDVI value (Lan et al., 2009). In-season estimation of yield (INSEY) was computed for the area as: INSEY= NDVI÷GDD, where, GDD is the number of Growing Degree Days greater than zero from seed emergence to sensing. The INSEY provides an estimate of daily biomass production or growth rate (Raun et al., 2005), and is therefore a vital determinant of final grain yield. GDD = [(daily maximum Temperature + daily minimum Temperature) ÷ 2] minus base temperature for maize (Lukina et al., 2001). The base temperature for maize is 10°C.

The maize was harvested from four rows by excluding two border rows from each side. A net plot size for each plot was 2.25 x 5.1 m (11.475 m^2). Stand counts per net plot were counted at the time of harvesting. Plant height, biomass yield, grain yield, harvest index, thousand kernel weight and other relevant agronomic traits were recorded at appropriate growth stages. Costs that vary among treatments were also assessed. The cost of Urea, the cost of labor required for the application, and cost for shelling were estimated by assessing the current local markets. The price of Urea (11200.00 ETB 100 kg^{-1}) and daily labors (35 ETB per man per day based on government's current scale in the study area), and the cost of maize shelling (100 ETB t ha^{-1}) were considered to get the total cost that varied among the treatments. On the other hand, non-varied costs were not included since all management practices were uniformly applied to each experimental plot. The grain yields harvested were adjusted down by 10% to reflect actual production environments. Gross revenue was calculated as adjusted grain yield multiplied by field price (7000.00 ETB t ha^{-1}) that farmers receive for the sale of the crop. The net benefit and the marginal rate of return were calculated as per standard manual (CIMMYT, 1988). Finally, combined analysis of variance was carried out using Gen Stat 15th Edition software, and Duncan's multiple range tests at P < 0.05 was used to compare treatment means (Duncan, 1955). Pearson's correlation analysis and regression were also performed to observe association and relationship between different variables as affected by different levels of N fertilizer applications.

RESULTS AND DISCUSSION

The combined analysis of variance revealed that applied N fertilizer at planting and side dressing significantly (P<0.01) affected grain yield, dry biomass, leaf area, harvest index and 1000 kernel weight (Table 1). There was also significant (P<0.05) difference between the applied N fertilizer on leaf area index. In addition, applied N at planting showed a highly significant (P<0.01) variation on plant height, leaf area, leaf area index, grain yield, dry biomass, harvest index and thousand kernel weight. Likewise, side dressing N rates showed significant (P<0.01) effect on leaf area, grain yield and dry biomass. Furthermore, applied N as side dressing significantly (*P<0.05*) affected leaf area index, harvest index and thousand kernel weight. On the contrary, the response of plant height to side dressing N rates did not show significant variations. NDVI values at V4 growth stage were significantly (P<0.01) affected by applied N rates at planting and side dressing (Table 2). Higher NDVI value at V4 was recorded when 25 and 75 kg N ha^{-1} was applied at planting and side dressing respectively, and it shows a decrease in NDVI value as N rate increased (Table 3).

The values of NDVI readings become greater while growth continues after V4, but it was small at the beginning (Figure 2a, b and Table 3). This was possibly low due to the initial growth stage/failure of canopy cover over the space and lack of early N stress. At later vegetative stages, the value improved most likely due to a more canopy cover. Increase in N level enhanced spectral vegetation indices which have been shown to be helpful for indirectly obtaining information such as photosynthetic efficiency and potential yield (Baral and Abhikari, 2015; Ngie et al., 2014).

A strong relationship between the NDVI values and grain yield of maize was observed (Figure 1). On the other hand, this shows the handheld sensor is one of the best instruments in indicating crop health and lack of

Table 2. Analysis of variance for NDVI value and INSEY under different levels of N fertilizer at Bako, western Ethiopia.

Source of variation	D.f.	F probability (p = 0.05)					
		NDVI at node			INSEY at node		
		V4	V6	V8	V4	V6	V8
Nitrogen at planting (N)	2	<.001	<.001	<.001	<.001	<.001	<.001
Nitrogen for side dressing (SD)	3	<.001	0.805	0.558	0.003	0.321	0.558
N * SD	6	<.001	0.881	0.910	<.001	0.109	0.910
Replication	2	0.085	0.110	<.001	<.001	0.249	<.001
Residual	22	–	–	–	–	–	–
Total							

d.f .= degree freedom, V4, V6 and V8 = vegetative growth stages at leaf four, six and eight, correspondingly.

Table 3. Effects of N fertilizer rate on leaf area, leaf area index, dry biomass, harvest index and thousand seed weight of quality protein maize at Bako, Ethiopia.

Nitrogen levels (kg ha-^{1})	Nitrogen rate for side dressing (kg ha-^{1})	Leaf area (cm^{2})	Leaf area index	Dry biomass (t ha^{-1})	Harvest index (%)	Thousand kernel weight (g)
0	19	5207^{ef}	2.22^{d}	18.3^{f}	36.1^{de}	314.9^{e}
0	38	5078^{f}	2.21^{d}	20.5^{e}	38.0^{a}	330.0^{bcd}
0	56	5337de	2.33^{cd}	21.7^{de}	37.5^{ab}	331.1^{bcd}
0	75	5163^{f}	2.28^{cd}	22.5^{cd}	36.0^{de}	322.5^{de}
25	19	5409^{d}	2.37^{c}	23.2^{bcd}	36.4^{d}	341.0^{a}
25	38	5636^{c}	2.51^{b}	24.2^{abc}	36.4^{cd}	335.0^{abc}
25	56	5797^{abc}	2.58^{ab}	24.5^{ab}	35.8^{de}	339.0^{ab}
25	75	5936^{a}	2.64^{a}	25.4^{a}	37.2b^{c}	327.1^{cd}
50	19	5792^{abc}	2.58^{ab}	23.8^{abc}	36.2d^{e}	322.2^{de}
50	38	5729^{bc}	2.55^{ab}	23.6^{bc}	36.4^{d}	326.3^{cd}
50	56	5860^{ab}	2.60^{ab}	24.1^{abc}	35.5^{e}	328.5^{cd}
50	75	5631^{c}	2.49^{b}	24.1^{abc}	36.5^{cd}	326.1^{cd}
LSD (5%)		153.8	0.11	1.57	0.71	9.1
CV (%)		1.6	2.7	4.0	1.2	1.6

stress that can give maximum yield, and minimize environmental contamination due to poor N management. Moges (2004); Raun et al. (2001) found that NDVI values were positively correlated with final grain yield. Further, Adis et al. (2015) indicated that there is a strong relationship between NDVI and grain yield of quality protein maize variety.

Likewise, a strong relationship between INSEY and grain yield was observed with 0.87 and 0.76 at V4 and V6 growth stages, correspondingly (Figure 2). Grain yield increased to 100 kg ha^{-1} N applied at V4; in a similar pattern the INSEY increased, and gradually results of both parameters declined. The smallest value of both grain yield and INSEY was recorded from the lowest N treatment at V4 growth stages (Table 4). As nitrogen level increased the NDVI values became higher at V4 and V6 growth stages. This result confirms that handheld NDVI sensor can predict grain yield with INSEY for maize. Stevens (2014) indicated that INSEY correlated with grain yield of maize.

There is also evidence of a strong relationship between wheat grain yield and INSEY (Raun et al., 2001). Furthermore, higher leaf area (5936 cm^{2}), leaf area index (2.64) and dry biomass (25.4 t ha^{-1}) were recorded from the use of 25 kg N ha^{-1} at the time of planting and 75 kg N ha^{-1} for side dressing 35 days after planting (Table 3). Higher thousand kernel weight (341 g) was attained from application of 25 and 19 kg N ha^{-1} at planting and side dressing, correspondingly. Conversely, lower leaf area (5078 cm^{2}) and leaf area index (2.21) were recorded from 38 kg N ha^{-1} treatments applied only as side dressing. Thousand kernel weight (314 g) and dry biomass (18.3 t ha^{-1}) were obtained from N applied at planting combined with 19 N kg ha^{-1} for side dressing. The lowest harvest index (35.5%) was, however, recorded from treatments receiving 50 and 56 kg N ha^{-1} at planting and side

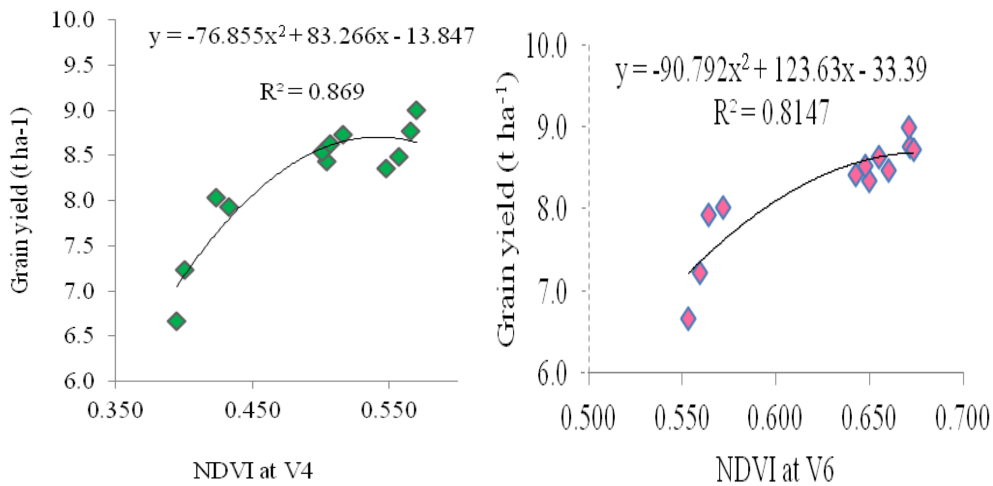

Figure 1. Grain yield of maize Vs. NDVI at V4 (left) and V6 (right) in 2016 at Bako, Ethiopia.

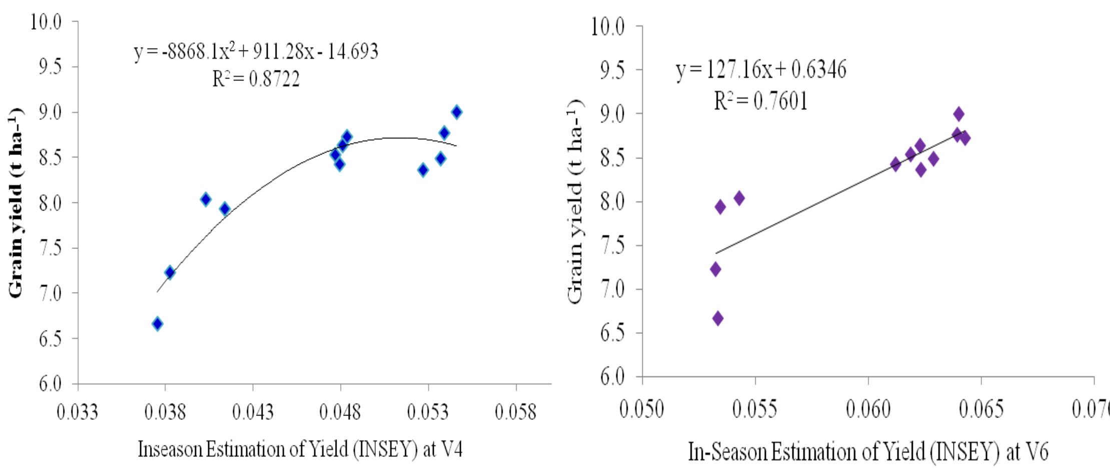

Figure 2. Grain yield Vs. INSEY at V4 (left) and V6 (right) stage of maize at Bako, Ethiopia.

dressing, respectively.

Applied N rates both at planting and side dressing also showed significant effects on mean grain yield of maize. The highest mean grain yields (9.0 t ha^{-1}) were obtained when 25 kg N ha^{-1} at planting with 75 kg N ha^{-1} for side dressing were used (Table 4). On the other hand, the lowest grain yield was recorded from plot receiving only 19 kg N ha^{-1} as side dressing compared to other treatment combinations.

Interrelationships between growth phenology and yield traits of maize

Applied N rates at planting were significantly associated with all growth phenology, yield and yield traits of maize except for TKW and HI which were non-significant and negatively associated (Table 5). On the other hand, side dressed N fertilizer showed a non-significant association with all yield traits except for grain yield. Significantly positive association (0.68, and 0.71) was also observed between applied N at planting, and NDVI at V4 and V6 growth stages. There is also higher correlation (0. 67 and 0.77) between applied N rates and INSEY at V4 and V6 growth stages. It means that, if the application of N rates is high, INSEY of yield at V4 and V6 growth stages of maize will increase. Likewise, significantly positive association (0.59, 0.48, 0.60, 0.77 and 0.76) was observed between applied N and PH, dry biomass, GY, LA and LAI correspondingly; whereas, N application at planting was negatively associated with HI of maize (-0.34). Moreover, the NDVI value and INSEY at V4, and

Table 4. NDVI reading, INSEY and grain yield of QPM in 206 at Bako, Ethiopia.

N rates at planting (kg ha-^{1})	Side dressing N rates (kg ha-^{1})	Grain yield (t ha-^{1})	NDVI at V4	NDVI at V6	INSEY at V4
0	19	6.7^g	0.395^f	0.55	0.038^d
0	38	7.2^f	0.401^f	0.56	0.038^d
0	56	7.9^e	0.433^e	0.56	0.041^c
0	75	8.0^{de}	0.423^e	0.57	0.040^c
25	19	8.4^{cd}	0.548^b	0.65	0.053^a
25	38	8.8^{ab}	0.566^a	0.67	0.054^a
25	56	8.7^{abc}	0.517^c	0.67	0.048^b
25	75	9.0^a	0.570^a	0.67	0.055^a
50	19	8.5^{bc}	0.557^{ab}	0.66	0.054^a
50	38	8.4^{bc}	0.504^{cd}	0.64	0.048^b
50	56	8.5^{bc}	0.501^d	0.65	0.048^b
50	75	8.6^{bc}	0.507^{cd}	0.66	0.048^b
LSD (5%)		0.30	0.013	0.044	0.0020
CV (%)		2.2	1.5	4.1	2.5

Table 5. Relationship between various growth phenological, grain yield and yield traits of maize at Bako in 2016, Ethiopia.

	N	SD	PH	DB	GY	TW	HI	LA	LAI	NDF	NDS	INF	INS
N		0.00	0.59**	0.48*	0.597**	0.063	-0.357*	0.774**	0.762**	0.68**	0.71**	0.67**	0.77**
SD			0.09	0.31	0.370*	0.014	0.051	0.192	0.229	-0.01	0.07	-0.03	0.06
PH				0.66**	0.700**	0.178	-0.454**	0.535**	0.483**	0.57**	0.65**	0.59**	0.56**
DB					0.897**	0.428*	-0.347*	0.613**	0.580**	0.61**	0.69**	0.64**	0.61**
GY						0.415*	-0.341*	0.765**	0.747**	0.78**	0.79**	0.78**	0.75**
TW							0.144	0.175	0.196	0.36*	0.40*	0.39*	0.39*
HI								-0.324*	-0.251	-0.20	-0.37*	-0.18	-0.29
LA									0.960**	0.79**	0.78**	0.75**	0.83**
LAI										0.78**	0.77**	0.76**	0.84**
NDF											0.87**	0.98**	0.93**
NDS												0.86**	0.91**
INF													0.91**
INS													

N= Nitrogen rate applied at planting; SD= Nitrogen applied as side dressing;PH= Plant height; DB= Above ground dry biomass; NDE= Normalized difference vegetative index at V8; INF= In season Estimation of Yield at V4; INS= In season Estimation of Yield at V6; INE= In season Estimation of Yield at V8, *and**= significant at 1 and 5 % probability level.

LAI and NSEY at V6 growth stage have significant correlation with grain yield (0.78 and 0.75). It means that, NDVI reading and calculated INSEY at V4, and LAI and NSEY at V6 vary together in the same direction for grain yield. The NDVI values at V4 with INSEY at V4 and V6 (0.98 and 0.93), and NDVI at V6 with INSEY at V4 and V6 growth stages (0.86 and 0.91) have higher correlation.

Partial budget analysis is indicated in Table 6. The highest net benefit ETB 53,590 ha^{-1} with marginal rate of return of 380 % and value to cost ration of ETB 29 per unit of investment were obtained when 25 and 38 kg N ha^{-1} were applied during planting, and side dressing (Table 6). The second higher net benefit ETB 51,590 ha^{-1} and marginal rate of return 363% with value to cost ration of ETB 39 per unit of investment were achieved when 25 and 19 N kg ha^{-1} were used during planting and side dressing, respectively. Conversely, minimum net benefit was attained from using only 19 kg ha^{-1} N applied as side dressing. The values to cost ratio ranged from ETB 14 to 68 per unit of investment of N application. Hence, the use of 25 kg N ha^{-1} at planting and 38 kg N ha^{-1} during side dressing was economically feasible for QPM production in the study area.

Conclusion

Determining the nitrogen status of the crop using NDVI

Table 6. Partial budget analysis for N fertilizer rates for QPM at Bako, Ethiopia.

Treatments NL (Kg ha^{-1})	Grain yield (t ha^{-1})	Adjusted grain yield (t ha^{-1})	Gross benefit (ETB)	TVC (ETB)	Net benefit (ETB)	Value to cost ratio	MRR (%)
0/19	6.7	6.0	42210	607.9	41602	68	
0/38	7.2	6.5	45360	1127.7	44232	39	510
25/19	8.4	7.6	52920	1330.5	51590	39	363
0/56	7.9	7.1	49770	1611.8	48158^{D}	30	
25/38	8.8	7.9	55440	1850.3	53590	29	380
50/19	8.5	7.7	53550	2065	51485^{D}	25	
0/75	8.0	7.2	50400	2119.7	48280^{D}	23	
25/56	8.7	7.8	54810	2334.4	52476^{D}	22	
50/38	8.4	7.6	52920	2584.8	50335^{D}	19	
25/75	9.0	8.1	56700	2842.3	53858	19	30
50/56	8.5	7.7	53550	3068.9	50481^{D}	16	
50/75	8.6	7.7	54180	3576.8	50603	14	

NL= nitrogen levels; TVC= Total Variable Costs; D= Dominated.

sensor is an effective way of managing N in maize producing farms. There were significant differences observed between applied N rates for various phenological growth, grain yield and yield traits of maize. Further, higher correlation coefficients (0.78) between grain yield, and NDIV and INSEY at V4 were observed. Moreover, significantly higher mean grain yield was obtained between 63 kg N ha^{-1} (25 kg N ha^{-1} during planting and side dressing with 38 kg N ha^{-1}) to 100 kg N ha^{-1} (25 kg N ha^{-1} at planting with 75 kg N ha^{-1} applied as side dressing). The NDVI sensor can be a very good indicator of N status of maize at early vegetative growth stage for N management in Bako. Application of 25 and 38 kg N ha^{-1} during planting and side dressing 35 days after sowing gave higher grain yield, and net benefit of ETB 53590 ha^{-1}. Thus, application of N fertilizer rate at 25 and 38 kg N ha^{-1} during planting and side dressing 35 days after sowing correspondingly is the best rate and is economically feasible to achieve best performance of the maize variety BHQPY545 in the study area. However, similar studies are required across various locations using different maize varieties to provide conclusive recommendations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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