NITROGEN FERTILIZER MANAGEMET FOR QUALITY PROTEIN MAIZE USING NORMALIZED DIFFERENCE VEGETATIVE INDEX SENSOR AT BAKO, WETSERN ETHIOPIA

M.Sc. Thesis

By

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VALIDATION OF NITROGEN FERTILIZER RATE FOR QUALITY PROTEIN MAIZE VARIETY USING NORMALIZED DIFFERENCE VEGETATIVE INDEX SENSOR AT BAKO, WETSERN ETHIOPIA

M.Sc Thesis

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By

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Jimma, Ethiopia

DEDICATION

This piece of work is dedicated to Engineer Dereje Bulto, who passed away during celebration of Oromo culture “Irrecha" at Bishoftu, East Showa zone of Oromia Regional State, Ethiopia in 2016 when I was doing this research. Oh! May God keep his soul in peace in the heavenly abode.

STATEMENT OF AUTHOR

First, I declare that this thesis is my own work and that all sources of materials used for writing it have been duly acknowledged. This thesis has been submitted to Jimma University College of Agriculture and Veterinary Medicine in partial fulfillment of the requirements for the Degree of Master of Science and is deposited at the library of the University to be made available to borrowers under the rules and regulations of the library. I declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief quotations from this thesis are allowable without requiring special permission provided that an accurate acknowledgement of source is made. Requests for permission for extended quotations from or reproduction of this manuscript in whole or in part may be granted by the head of the Department of Horticulture and plant Sciences or by the Dean of the School of Graduate Studies where in his or her judgment, the proposed use of the material is for a scholarly interest. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author, Hailu Feyisa Tasisa, was born in Jeldu District in West Showa Zone of Oromia Regional State, Ethiopia on 19 December 1984. He attended elementary and secondary education at Jeldu and Ginci Senior Secondary School from 1991 to 2003.

In 2004, he joined Ambo University and graduated with Diploma in General agriculture in June 2006. He was employed in different governmental and non-governmental organizations since 2007 like The Hunger Project Ethiopia, Generation in Action development, Farm Africa and Oromia Agricultural Office and finally Oromia Agricultural Research Institute of Bako Agricultural Research Center. He joined Jimma University College of Agriculture and Veterinary Medicine in advanced standing Bachelor of Science program in 2009 and graduated with the Degree of Bachelor of Science in Plant Sciences in June 2011. Currently, he is an employee of Bako Agricultural Research Center in Cereal Crops Technology Generation Team as researcher (agronomist) until he joined Jimma University College of Agriculture and Veterinary Medicine in September 2015 to pursue his education leading to Master of Science Degree in Agronomy.

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ACRONYMS AND ABBREVIATIONS

CIMMYT	International Center for Wheat and Maize Improvement
CIR	Color Infra Red
CSA	Central Statistical Agency
DFATD	Development of Foreign Affairs Trade & Development
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
FAOSTATA	The Food and Agriculture Organization Corporate Statistical
GDD	Growing Degree Days
Kg	Kilogram
MRR	Marginal Rate of Return
NIR	Near Infra Red radiation
NUE	Nitrogen Use Efficiency
QPM	Quality protein maize
R	Red radiation
t	tons

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ABSTRACT

Crop production is a complex system that integrates physical, chemical and biological processes and is managed under increasing economic and ecological constraints. Maize is one of a high valued crop in Ethiopia, especially in western regions of the country where it is the dominant crop and is produced in a number of agro-ecologies in the region. Despite tremendous yield potential, its productivity is constrained by blanket application of inorganic nitrogen (N) fertilizers. This experiment was conducted during 2016 cropping season at Bako, western Ethiopia with the objectives of validating and determine the optimum nitrogen fertilizer rate for side dressing supported by normalized difference vegetative index (NDVI) sensor for quality protein maize for efficient management of N to optimize grain productivity of quality protein maize. The trials were laid out in a factorial randomized complete block design with three rates of nitrogen fertilizer (0, 25 and 50 kg N ha^{-1}) applied at planting and four rates of estimated N (19, 38, 56 and 75 kg N ha^{-1}) applied as side dressing. The mean yield components of quality protein maize variety were significantly affected by application of nitrogen rates. Significantly higher mean grain yield of quality protein maize was obtained between 63 kg ha^{-1} N (25 kg ha^{-1} at planting with 38 kg ha^{-1} side dressing) up to 100 kg ha^{-1} N. Significant differences were also observed on measured NDVI and In-season estimation of yield (INSEY) at node initiation (V4) growth stage of maize. Grain yield shows a higher correlation coefficients (0.78**) with NDIV and INSEY at V4 growth stage of maize. The NDVI reading and calculated INSEY at node elongation growth stage have strong correlation with grain yield (0.79** and 0.75**). Overall, application of 25 kg N ha^{-1} fertilizer rates at planting with 38 kg N ha^{-1} side dressing had better net benefit of ETB 53590 ha^{-1}. *Therefore, application of 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} for side dressing is recommended for quality protein maize variety in Bako area and similar agro-ecologies.*

Key words: *INSEY, maize, NDVI, nitrogen fertilizers, QPM*

1. INTRODUCTION

Crop production is a complex system that integrates physical, chemical and biological processes and is managed under increasing economic and ecological constraints (Schroder *et al*., 2000). Maize (*Zea mays* L.) is one of the most important crops worldwide. It is originated in Central America and introduced to West Africa in the early 1500s by the Portuguese traders (Dowswell *et al*., 1996). Later, this crop was introduced to Ethiopia during the 1600s to 1700s (Haffangel, 1961).

Currently, Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2012). In the country, maize is the major staple crop leading all other cereals in terms of production and productivity, and only surpassed by *tef* in terms of area (CSA, 2014a). According to a 2013/14, meher season post harvest crop production survey, total land areas of about 12.4 million hectares were covered by grain crops. Out of this areas, 79.38% (9,848,745.96 hectares) under cereals, maize covered 16.08% (about 1,994,813.80 hectares), and 25.81% (64,915,40.29 tons) grain yields (CSA, 2014).

Millions of people in Ethiopia depend on maize for their daily food especially where maize is the major crop (Mosisa *et al*., 2002). However, normal maize varieties cannot sustain acceptable growth and adequate health because of low content of essential amino acids. Meat, eggs, milk, and legumes are known to be good sources of essential amino acids. But animal proteins are not affordable for a large segment of small-scale farmers. To overcome this problem, scientists have used conventional breeding methods and developed maize cultivars that have higher lysine and tryptophan content than conventional maize genotypes and has been named as "quality protein maize" (Adefris *et al*., 2015). Research on quality protein maize (QPM) in Ethiopia was launched in 1994 and released QPM hybrids for maize agro-ecologies of Ethiopia (Adefris *et al*., 2015).

Despite tremendous yield potential, maize productivity remains low in Ethiopia. Current national average grain yield is 3.3 t ha^{-1} (CSA, 2014). This is very low compared to the developed countries average yield of 10.3 t ha^{-1} in USA, 9.7 t ha^{-1} in Germany, 8.4 t ha^{-1} in Canada, 4.96 t ha^{-1} in South Africa and 5.2 t ha^{-1} is world grain average (FAOSTAT, 2012). This much yield gap is attributed to a number of factors like declining of soil fertility, poor agronomic practice, limited use of input, poor seed quality, frequent occurrence of drought, disease, and others (CIMMYT, 2004).

Proper N application rates are critical for meeting crop needs, and give considerable opportunities for improving N use efficiency (Dhugga and Waines, 1989; Blankenau *et al*., 2002). Most often, growers striving to meet the crop's N requirements frequently over fertilize. Conversely, excessive application of nitrogen is uneconomical, environmentally unsafe and potentially detrimental to the crop (Westermann and Kleinkopf, 1985). On the other hand, farmers in developing countries apply insufficient quantities of N fertilizer due to less access or prohibitive prices or they ill-apply the fertilizers in timing and rate (Le Gouis *et al*., 2007).

Thus, improving crop production and productivity requires the use of nitrogen fertilizer, with great emphasis on the efficiency of N utilization. Therefore, considering the high cost and the detrimental effects of nitrogen deficiencies on crop production on one hand and the environmental hazards due to its overdose, cause the efficient use of nitrogen in crop production has become a desirable agronomic, economic, and environmental goal.

There is a very wide range of optical sensors applied in agriculture, which goes from sensors used to analyze soil attributes to sensors installed in combines to measure protein content in grains while they are being harvested (Povh and Anjos, 2014). Hand held normalized difference vegetative index (NDVI) optical sensor technology is one of a prominent example of sensors which enables us to measure, in real time, a crop's nitrogen levels and variably apply the "prescribed" nitrogen requirements. The use of hand held NDVI sensor would bring precision agriculture to African smallholders, improving crop productivity, increasing returns on N fertilizer and reducing the risk of environmental pollution (Tolera *et al.*, 2015).

Farmers in the utmost part of Ethiopian use only basal application of N once in a blanket recommendation, which can result in loss of N through leaching and volatilization, reduced N use efficiency and yield. Most growers in the Bako, Western Ethiopia do not apply side dress N as required by the maize; it might be possible to adjust grower practices if this method improved N management. Sripada (2005) showed that a more accurate method of determining side dress N requirements has the potential to improve nitrogen use efficiency and minimize N losses to the environment. Scharf and Lory (2002) and Sripada *et al*. (2005) demonstrated significant yield responses to N applied at seven leaf vegetative growth stage (V7) and tasselling, respectively. Carranca (2012) reported crops are often fertilized with large amounts of N fertilizer, but only a small fraction of this fertilizer roughly 5% to 50%, is taken up by the plants. Hence, much of the work associated with making fertilizer recommendations have not considered the potential of focusing in-season prediction of grain yield and the use of NDVI sensors to upturn economic as well as environmental health.

On the other hand, currently skyrocketed prices of synthetic fertilizer have made it difficult for smallholder farmers in Ethiopia to use higher amount of inorganic N for crop production. However, the released QPM varieties would be very important to have site specific fertilizer management packages to increase production and productivity for the benefit of producer in Ethiopia in terms of nutrition, economic and reduce environmental protection. Site-specific nutrient management aims at "doing the right thing, at the right place, at the right time", and when used in combination with information technologies it defines "precision agriculture" (Bongiovanni and Deboer, 2004).

Recently there was an attempt by Tolera *et al.* (2014; 2015) and Adis *et al.* (2015) in Western parts and rift valley of Ethiopia, on in-season N fertilizer calibration using hand-held NDVI sensor for QPM varieties, which is promising to use for quality protein maize by validating the result. To this point, BHQPY545 variety is among the recently released QPM variety for humid mid-altitudes. There is a need to validate the result of the calibrated N fertilizer rate and recommending side dressing nitrogen rate for the variety in the study area. Hence, the current research was initiated to address the objectives of validating and determine the optimum nitrogen fertilizer rate for side dressing supported by normalized difference vegetative index sensor for quality protein maize.

2. LITERATURE REVIEW

2.1 Biology of Maize

Maize is a tall, monoecious, annual grass varying in height from 1 to 4 meters (Watson & Dallwitz, 1992). The main stem is made up of clearly defined nodes and internodes. Internodes are wide at the base and gradually taper to the terminal inflorescence at the top of the plant. Leaf blades are found in an alternating pattern along the stem. Maize is a unique grass as both male and female flowers are borne on the same plant but are located separately. The tassels or staminate (male) inflorescence form large spreading terminal panicles that resemble spike like racemes. Pollen is shed from the tassel and is viable for approximately 10 to 30 minutes as it is rapidly desiccated in the air (Kiesselbach, 1980). Maize plants shed pollen for up to 14 days. The reproductive phase begins when one or two auxiliary buds, present in the leaf axils, develop and form the pistillate inflorescence or female flower (Purseglove, 1972). The auxiliary bud starts the transformation to form a long 'cob' on which the flowers will be borne. From each flower a style begins to elongate towards the tip of the cob in preparation for fertilization. These styles form long threads, known as silks (Purseglove, 1972). Styles may reach a length of 30 cm, the longest known in the plant kingdom. Individual maize kernels, or fruit, are unique in that mature seed is not covered by floral bracts (glumes, lemmas, and paleas) as in most other grasses, but rather the entire structure is enclosed and protected by large modified leaf bracts, collectively referred to as the ear (Hitchcock and Chase, 1951). The pollen of maize, a protandrous plant, matures before the female flower is receptive (Purseglove 1972). This may have been an ancient mechanism to ensure cross-pollination, but is no longer considered conducive to modern agricultural practices. However, decades of conventional selection and improvement have produced many maize varieties with similar maturities for both male and female flowers, to ensure seed set for agricultural proposes.

All maize varieties follow same general pattern of development, although specific time and interval between stages and total number of leaves developed may vary between different hybrids, seasons, time of planting and location. The various stages of maize growth are broadly separated into two groups: vegetative and reproductive. The point that separates these two groups is the appearance of silks (Ritchie *et al*., 1993).

Vegetative (V) stages are identified by the number of collars present on the plant. The leaf collar is the light-colored collar-like "band" located at the base of an exposed leaf blade, near the spot where the leaf blade comes in contact with the stem of the plant. Leaves within the whorl, not fully expanded and with no visible leaf collar are not included. For example, a plant with 3 collars is considered V3, however, there may be 5 to 6 leaves showing on the plant. Full development of the first leaf is known as V1. Likewise fully development of the second, third, fourth, fifth and nth leaf is known as V2, V3, V4, V5 and V(n) leafs respectively (Ritchie *et al*., 1993).

On the other hand, reproductive (R) occurs when silks are visible outside the husks and known as R1, followed by blister (R2), milk (R3), dough (R4), dent (R5) and black layer or physiological maturity (V6). The plant is most vulnerable to stress during silking, when important pollination events are occurring. As the reproductive stages progress, the effect of stress on seed weight will decrease, while the effect on seed number will be minimal after R2. Highest yields will be achieved in areas where environmental conditions are favorable for these growth stages, especially R1. Unfavorable conditions early in the season will limit leaf size, which will decrease photosynthesis, while stress later in the season can affect pollination in the form of kernel size and number (Ritchie *et al*., 1993).

2.2 Agro-ecologies of Maize in Ethiopia

In Ethiopia, maize grows under a wide range of environmental conditions between 500 to 2400 meters above sea level. The mid-altitude, sub-humid agro-ecology is the most important maize producing environment in Ethiopia (Kebede *et al*., 1993). This region is considered to be the major maize growing zone in the country. The region lies at an altitude of between 1000 to 1800 m above sea level and receives a fairly reliable average annual rainfall (1000 to 1500 mm/year), rendering it a region of high potential for maize production (Gemech *et al*., 2016). According to the 2012 Central Statistical Agency (CSA) data, the top ten maize growing zones of Ethiopia are East Wallaga, West Wallaga, East Showa, Illubabor, Jimma, North Gondar, West Gojjam, West Harerge, West Showa and Arsi.

2.3 Maize production and Research in Ethiopia

2.3.1 Conventional maize production and Research in Ethiopia

Maize has been considered globally as the most important agricultural grain which is staple food in many countries and feed to livestock. It grows from sea level to over 3000 meters above sea level (Dowswell *et al*., 1996). It has the highest average yield per hectare and is third after wheat and rice in area and total production in the world (Mosisa *et al*., 2002). Global production exceeds 600 metric tons, with about 60% produced in the developed countries and the rest is grown in countries of Africa, Latin America, and southern Asia with a large proportion being produced in the tropics and subtropics (Donald and Nicol, 2005).

It is estimated that by 2050, the demand for maize in developing countries will double, and by 2025 maize will have become the crop with the greatest production globally (FARA, 2009). According to Abuja Summit meeting in 2006 on Food Security in Africa, maize was identified among a strategic commodity for achieving food security and poverty reduction. Thus, there is a call to promote maize production on the continent to achieve food self-sufficiency by 2015 (AUC, 2006). It has been considered globally as the most human diet and livestock feed in large parts of the world (Negi, 2014). Maize grain has greater nutritional value as it contains 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3.0% sugar and 1.7% ash. In addition to food and feed consumption, it has extensive range of industrial applications as well; from food processing to manufacturing of ethanol (Chaudhary, 1983).

In Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowlands to the highlands areas (Kebede *et al*., 1993). The total annual production and productivity exceed all other cereal crops, though it is surpassed by teff in area coverage (CSA, 2014). Therefore, considering its importance in terms of wide adaptation, total production and productivity, maize is one of the high priority crops to feed the ever increasing population of the country.

In recent years (2003 to 2012), yield gains of 5.3% per annum were achieved while the rate of growth in area planted to maize was about 4.7% per annum, compared to the previous period but overall gains of production were 10.6% per annum (Tsedeke *et al*., 2013). This means that recent increases in production were more due to increases in productivity rather than increases in the area. Further the authors reported that the current yield is upwards of 3 MT per ha, second highest in Sub-Saharan Africa (SSA) after South Africa. Yield has doubled in the 10 years between 2003 and 2012; growths in productivity and production were more rapid and consistent particularly since 2004. Compared to the 1960s the share of maize consumption among cereals more than doubled to nearly 30% in the 2000s, whereas the share of teff, a cereal that occupies the largest area of all crops in Ethiopia, declined from more than 30% to about 18% during the same period (Demeke, 2012).

The popularity of maize in Ethiopia is partly because of its high value as a food crop as well as the growing demand for the stover as animal fodder and source of fuel for rural families. Approximately 88 % of maize produced in Ethiopia is consumed at home as food, both as green and dry grain (Tsedeke *et al*., 2015). No other cereal crop produced reaches to this level in terms of retention for home consumption (Moti *et al*., 2015). Maize for industrial use has also supported growing demand. Very little maize is currently used as feed but this is changing in order to support a rapidly growing urbanization and poultry industry (Tsedeke *et al*., 2015). Thus, for smallholder farmers in maize-based systems, their perception on own food security status is directly related to the amount of maize harvest they produced in a given year, which is again related to maize productivity influenced by factors such as varieties used and crop management efforts put forth.

Improved varieties play a great role in increasing maize productivity on currently cultivated land. The National Maize Research Project has developed a number of improved maize varieties through different breeding methodologies (Benti *et al*., 1993; Mosisa *et al*., 2002). The improved maize varieties include open-pollinated varieties and different types of hybrids (top cross, three-way cross and single cross hybrids).

Modern varieties undoubtedly, the maize story in Ethiopia is largely homegrown and improved maize germplasm has played a key part in catalyzing change in production practices by replacing traditional varieties with input-responsive, stable and high yielding MVs. The Ethiopian National Agricultural Research System has released a total of 61 maize varieties between 1973 and 2013; 39 of these were hybrids and 22 were open pollinated varieties (OPVs). The first hybrid (BH140, in the early to intermediate maturity group) was released in 1988, followed by a late maturing hybrid (BH660) in 1993, and BH540 and Jabi (PHB3253) in 1995 (Tsedeke *et al*., 2015).

Moreover, new technologies with respect to intercropping, soil and water conservation, cultural practices and other cropping systems were developed (Mosisa *et al*., 2002). Improved maize technologies are developed at different research centers situated in different agro-ecologies. Bako, Awassa, Jimma and Areka research centers are testing centers for mid-altitude sub-humid agro-ecology and transitional zones. Ambo, Alemaya, Adet, Arsi-Negele, Kulumsa, Areka and Holetta research centers are testing centers for high land and transitional zones. Melkassa, Zwai, Babile, Jijiga, Moyale, Sirinka, Mekele, Dhera, Yabelo, Tuka, and Selaklaka are testing centers for moisture stress areas. Pawe and Abobo research centers are important hot spot areas for screening germplasm against Striga and maize streak virus, respectively, and also evaluate and select maize germplasm for the low altitude sub-humid agro-ecology in collaboration with the coordinating center (Mosisa *et al*., 2002).

2.3.2 Quality protein maize production and Research in Ethiopia

Millions of people in Ethiopia depend on maize for their daily food especially where maize is the major crop (Mosisa *et al*., 2002). However, conventional maize varieties cannot sustain acceptable growth and adequate health because of low content of essential amino acids. To alleviate the problem, development of quality protein maize (QPM) varieties with high lysine and tryptophan content has been enhanced in the 1900s (Mosisa *et al*., 2002). According to Adefris *et al*. (2015), an important factor that determines protein quality is how closely the ratio of essential amino acids present in a particular food item matches the human requirement. Research on quality protein maize is of recent history in Ethiopia. It was launched in 1994 and released BHQP542 in 2001 followed by Melkasa-6Q, BHQPY545, AMH760Q, MHQ138 and Melkasa-1Q until 2014 for the three maize agro-ecologies of Ethiopia (Adefris *et al*., 2015).

Adefris *et al.* (2015) reported dissemination of QPM varieties in developing countries where maize is the dominant dietary source of energy and protein in four eastern African countries, including Ethiopia, during 2003-2010, to address the issues of protein under nutrition. Research on QPM is of recent history in Ethiopia. It was launched in 1994 and released BHQP542 in 2001 followed by Melkasa-6Q, BHQPY545, AMH760Q, MHQ138 and Melkasa-1Q until 2014 for the three maize agro-ecologies of Ethiopia (Table 1).

Table 1. QPM varieties released in Ethiopia and their important agronomic and adaption characteristics

Variety	Altitude (m)	Rain fall (mm)	Days to maturity	Potential yield (t ha^{-1})	
				On-station	On-farm
BHQP548	1000-1800	1000-1200	145	7.5-8.5	6.5-7.5
BHQPY545	1000-1800	1000-1200	144	8.0-9.5	5.5-6.5
BHQPY542	1000-1800	1000-1200	145	8.0-9.0	5.0-6.0
AMH760Q	1600-2200	1000-1500	160	9.0-12.0	6.0-8.0
Melkasa6Q	1000-1750	500-800	135	4.5-5.5	3.0-4.0
MHQ138	1000-1800	600-1000	135	7.0-8.0	5.5-6.0
Melkasa1Q	800-1500	400-700	90	3.0-4.5	2.5-3.5

Source: Adefris *et al.* (2015)

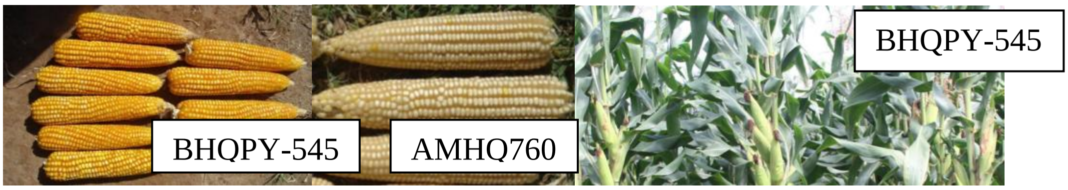


Figure 1. Physical appearance and performance of some QPM varieties under field conditions

The effort, spanning over the last decade, involved collaborative CIMMYT/donor funded projects with large components of flow through funding to enable the full participation of regional NARS. CIMMYT remained the major source of global QPM germplasm and hence QPM development in the region and Ethiopia heavily depended on the large pool of QPM source germplasm available at CIMMYT. Support from DFATD to Ethiopia has continued under the Nutritious Maize for Ethiopia (NuME) project since 2012.

Current QPM breeding strategies at CIMMYT focus on pedigree breeding, whereby the best performing inbred lines, complementary in different traits, are crossed to establish new segregating families. New inbred lines are developed from these segregating families in the same process as from the broader based populations. Three types of crosses provide a choice of breeding strategies: QPM by QPM, QPM by Normal and QPM by Normal Backcross Conversion (of the normal genotype to QPM using at least three backcross generations)(Krivanek *et al*.,2007).

A major challenge with QPM is the dissemination of the material into the farmer's field. The dissemination and adoption of QPM is still lagging behind normal endosperm maize especially in regions such as sub-Saharan Africa where it is needed most including Ethiopia (Aman *etal.*,2016). In sub Saharan Africa, total maize area is estimated at 30 million hectares (FAOSTAT, 2012), and only less than 1% (or 200 000 hectares) was estimated to be under QPM. Unfortunately, in the early 1990's the CIMMYT QPM breeding program was discontinued and as such the critical step of promoting this improved material was also severely limited. Since the late 1990's however, the Nippon Foundation of Japan and then later the Canadian International Development Agency (CIDA) have funded the continued improvement and promotion of QPM in several developing countries (Gemechu, 2016).

2.4 Nutritional Importance of Quality Protein Maize

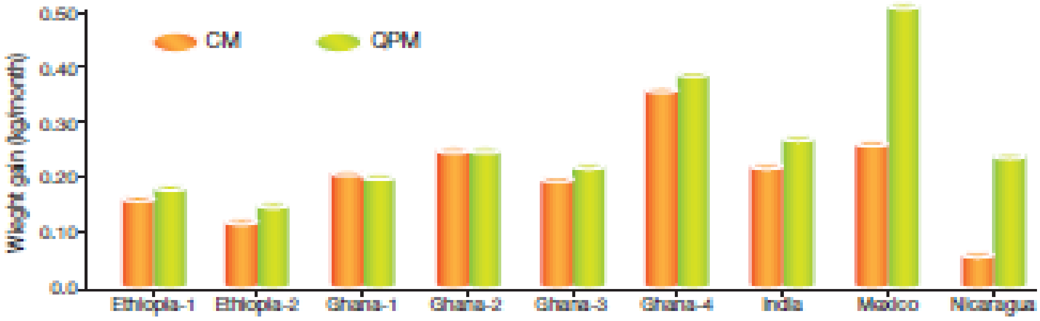
Quality protein maize (QPM) variety is a cheap source of protein, given that farmers can grow, manage, harvest, and consume it in the same way they do for CM varieties. Despite the nutritional differences (Table 2 and Fig. 2), QPM varieties look and perform like CM varieties (Fig. 1) and one cannot visually distinguish between the two by the physical appearance of the plants or their ears and grains alone (Adefris *et al.,* 2015). Further, the authors stated that due to the significantly enhanced levels of tryptophan and lysine it contains, QPM also reduces by half the amount of maize that needs to be consumed to get the same amount of biologically usable protein from a maize diet.

Table 2. Comparison of the protein biological value of normal and *opaque-o2* maize with milk.

Maize Varieties	Protein content (%)
Conventional maize	40
QPM (*o2* maize)	80-90
Milk	90-100

Source: Vivek B.S. *et al. (*2008).

Akalu *et al*. (2010) reported the positive effect of QPM on both the height and weight of children aged 7 to 56 months in Sibu Sire districts, East Wallaga zone, Western Ethiopia where maize is a dominant crop. He found that children consuming CM showed a decrease in both height-for-age and weight-for-age over time, while children fed QPM did not show significant change in height-for-age but their weight-for-age increased marginally. Farmers preferred *injera* made from QPM over CM *injera* due to its softness and longer shelf life (Fig. 3). QPM porridge was also described as smoother than porridge prepared with CM. Mothers noted that QPM developed less of a sour taste when fermented than CM, making it more palatable to children. Children also liked the taste of “green” QPM grain over the taste of “green” CM because of its perceived sweetness; also, children did not feel hungry for a longer time after consuming QPM-based food (Akalu *et al*., 2010). Pigs fed on QPM grew 2.3 times faster than pigs of the same age fed on the same quantity of normal maize (Fig. 4). QPM fed chicken grew faster than normal maize (Fig. 4), with higher feed efficiency (Vivek *et al.*, 2008).



Source: Adefris *et al*. (2015)

Figure 2. Rate of weight increase among children receiving QPM vs. CM

Figure 3. Injera prepared from quality protein maize variey

Source: Vivek *et al*. (2008)

Figure 4. Pigs and Chicken fed high lysine/tryptophan maize compared with its sibling fed normal maize

2.5 Nitrogen fertilizer in Maize Production

Nutrient deficiency is one of the major problems hampering the development of agriculture in many parts of the world (Fageria and Baligar, 2005). It is projected that some 30 to 50% of the increase in world food production since the 1950s is attributable to fertilizer use (Higgs *et al*., 2002). Nevertheless, many farmers refrain from using fertilizer due to escalating costs, 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 supply of food for human being and feed for animals are more limited to nitrogen (N) than any other element, since large amount of N is lost through different process like denitrification, leaching, volatilization and removal by crops (Acquaah, 2002). The maximum N uptake by maize occurs during the month prior to tasselling and silking (Hammons, 2009). Since yield is likely to be low under N stress during silking, coincidence of N availability in soil solution, and plant uptake demands are crucial to unlocking the potential of modern hybrids. Maize production under N stress have been reported widely to cause poor kernel formation, increased abortion and ultimately resulted in to low grain yield (Andrade *et al*., 2000).

2.5.1 Importance of Nitrogen fertilizer application in Maize Production

Increased crop productivity has been associated with a 20-fold increase in the global use of N fertilizer use during the past five decades (Glass, 2003) and this is expected to increase at least 3-fold by 2050 (Good *et al.,* 2004). It plays a pivotal role in several physiological processes inside the plant. It is also a fundamental to establish the plants photosynthetic capacity (Hageman and Below, 1984); it prolongs the effective leaf area duration, delaying senescence; it is important for ear and kernel initiation, contributing to define maize sink capacity; and it helps to maintain functional kernels throughout grain filling, influencing the number of developed kernels and kernel final size (Jones *et al.,* 1996). Nitrogen limiting conditions produce several restrictions to plant development; delaying silking, decreasing pre-anthesis crop growth rate, dwindling leaf area index at flowering and accelerating leaf senescence rates throughout the life cycle (Wolfe *et al.*, 1988).

Compared to other cereals, maize requires higher inputs of nitrogen fertilizer. However, high N applications are costly and can pose serious threat of nitrate accumulation in surface and groundwater (Errebhi *et al*., 1999; Hopkins *et al*., 2008). Fertilizer application to maize by most farmers in many places, particularly in Bako, Western Ethiopia is based on blanket recommendation. These recommendations disregard the specific physico-chemical characteristics of the varied soils on which the crop is grown, as well as the dynamic nature of soil nutrient status.

A well considered and efficient way of application of N to crops contributes to the efficient use of N in cropping systems. The use of mineral fertilizer has spread radically over the last 60 years. The use of fertilizer rose from 3.6 million tons in 1950 to 85 million tons in 1990 (Ayoub, 1999). The increasing use of N and other fertilizers was one of the main factors contributed to the increased average world production. To sustain this production until 2030, the consumption of chemical fertilizer will probably double (Brown, 1996).

2.5.2 Response of maize to In-season Nitrogen fertilizers

Russelle *et al*. (1983); Jokela and Randall (1997) stated that fertilizer N recovery by the crop may sometimes be greater when N application is delayed compared to application at planting. This is probably due to greater exposure of N applied at planting to a range of possible loss processes (immobilization, leaching, denitrification, and clay fixation) at a time when N uptake rates are relatively low. For irrigated corn grown on sandy soils, side dress applications tend to produce higher yields than pre-plant applications (Bundy *et al*., 1983; Rehm and Wiese, 1975). On the other hand, Jung *et al*. (1972) observed equivalent yields when a single N application was made from 5 to 8 weeks after planting, but yields began to decline when N application was delayed until the ninth week or later. However, late N applications in rainfed production systems might behave differently. For example, N may not be absorbed by the root system when rainfall is limited after N applications.

Studies in Kentucky under rainfed conditions by Miller *et al*. (1975) obtained a large yield response to N and equivalent yields regardless of whether N was applied in May, June, July, or a May–June split. Randall *et al*. (1997) found equivalent corn yields with all N fertilizer applied at planting or with one-third applied at planting and the remaining delayed until sixteen leaf growth stage (V16) in southern Minnesota.

Conventional methods of estimating in-season N requirements for maize are based on soil testing (Magdoff, 1991), plant tissue N concentrations (Tyner and Webb, 1946), chlorophyll concentrations, or leaf greenness (Varvel *et al*., 1997). However, these methods require multiple samples to be taken, labour intensive, can be expensive and time consuming, and often produce inaccurate estimates of N requirements (Blackmer and Schepers, 1996). Thus, faster, possibly more economical, accurate and timely information on crop input parameters both in space and time is important for collecting crop information and estimates of N requirements. This is because of the environmental and economic impacts of agriculture and the need to produce more food more efficiently to feed a growing population of the world (Sripada, 2005).

2.5.3 Nitrogen Loss

Not all the nitrogen applied is taken up by the crop, since large amount of N is lost through denitrification, leaching into the groundwater, volatilization, surface soil runoff and removal by crops (Acquaah, 2002). Denitrification occurs when fields are waterlogged. Under anaerobic conditions, NO^{-}_{3} serves as the electron acceptor for microorganisms and is reduced to gaseous N_2 forms. Ammonia volatilization is another process in which N is lost in a gaseous form. Volatilization occurs primarily when urea-based fertilizers or animal manures are not incorporated into the soil. Under warm, moist conditions, ammonia is lost along with water vapor from the soil surface (Nelson, 1982). Leaching occurs when NO^{-}_{3}, which is water soluble, moves through the soil profile with rainfall or through subsurface drainage. Ammonium may leach from sandy soils (Stevenson, 1982). Denitrification, volatilization, and leaching are all controlled in part by weather conditions encountered during the growing season, making N losses often unpredictable. Estimates of crop N requirements need to be assessed in-season due to this variability.

Apart from the inherent genetic characteristics of the crop, N loss can be minimized by matching the N supplying capacity of soil with the N uptake pattern of corn (Sripada, 2005). The maximum N uptake by maize occurs during the month prior to tasselling and silking (Hammons, 2009). Since yield is likely to be low under N stress during silking, coincidence of N availability in soil solution, and plant uptake demands are crucial to unlocking the potential of modern hybrids. Indeed, poor kernel formation, increased abortion and ultimately low grain yield under N stress have been reported widely (Andrade *et al*., 2000).

2.5.4 Methods of Nitrogen Application

Pre-season blanket fertilizer recommendation of nitrogen fertilizer application rates for maize based on differences in soil and prior yields have been shown to be unreliable. While, yield potential and soil differences are important, many other factors such as rainfall and nitrogen leaching affect N loss and availability. Alleviating fertilizer N losses in agriculture can help farmers to apply the needed amount and reduce the environmental pollution reported. Increased cereal NUE is a systems approach that uses varieties with high harvest index, incorporated NH_4-N fertilizer, application of prescribed rates consistent with in field variability using sensor based systems within production fields, low N rates applied at flowering and forage production systems (Raun and Johnson, 1999).

As evident from many past and on-going studies, maize N requirements are usually more efficiently achieved by multiple fertilizer applications rather than one single application (Blackmer *et al*., 1996; Andraski *et al*., 2000). Tolessa *et al*., (1994) suggested that the best use of nitrogen is obtained when 50% of the total requirement is applied at sowing and the remaining 50% is given as top dressing. According to this author, the other option is application of the total requirement in three equal splits at sowing, knee-height and flag leaf emergence. The best time for the first top dressing is 30-35 days after emergence just after the first weeding and again 60-65 days after emergence just after the second weeding or before tasseling (with the emergence of the flag leaf) (Tolessa *et al*., 1994). There is general agreement on the value of applying N in split applications (Russelle *et al*., 1983; Blackmer *et al*., 1989; Jokela and Randall, 1997). However, there is considerable debate over the methods and/or processes used to quantify the second split N application and this is an area of active research. Much of the work associated with making fertilizer recommendations has not considered the potential focusing in-season N management of potential grain yield use of NDVI sensors to upturn economic as well as environmental health.

2.5.5 Nitrogen Use Efficiency

Despite the great amount of data and information developed on N management for grain crops, worldwide nitrogen use efficiency (NUE) has been estimated at only 33%, where NUE = [(N removed in grain)-(N removed from soil + N deposited in rainfall)]/(fertilizer N applied) (Mulluk, 2012). Therefore, a large proportion of N is lost as a contaminant in to the air, aquifers or surface water (Assimakopoulose *et al.*, 2003). Raun and Johnson (1999) reported that low NUE can be attributed to several factors including, denitrification, surface runoff of fertilizer, volatilization of NH_3, and NO_3 leaching. The authors further suggested that increases in NUE can occur with better management practices, such as utilization of crop rotations including legumes, hybrid/variety breeding for selection of higher NUE, the source of fertilizer, the rate of fertilizer, time of fertilizer application, the placement of fertilizer in relation to the crop, and midseason and foliar applications of N. N applied closer to maximum crop use is less likely to be lost and more likely to be taken up by the crop and potentially available to support kernel set at flowering and late-season grain development. Another author, Vitosh *et al*. (1995) stated that one practices that has been proposed to improve NUE on sandy soils (where leaching is a concern) and on poorly drained soils (where denitrification may occur) is a split application of N fertilizer, which involves applying a small portion of pre-plant N fertilizer combined with a large portion of N as side dress after the crop has been established (Welch *et al.*, 1971; Ma *et al.*, 2005). The need for NUE improvement promotes the continuous development of knowledge and field experiments, and the evaluation of new technologies, such as those associated with precision agriculture.

Precision farming can increase NUE through the application of N in a precise manner to treat by plant variability with fertilizer (Raun and Johnson, 1999). Solie *et al*. (1996) stated that the optimum field element size is one that provides the most precise measure of nutrient where levels of that nutrient change with distance. They further stated that variable rate applications on scales larger than 1.96 m^2 will result in a grid too coarse and thus misapply inputs. This indicates that the management zones have limitations as they do not match within field variability. Scharf *et al*. (2005) stated that spatially intensive information for N management has greater potential benefits than management zones. Individual plant N fertilization is also critical because plant to plant variability in corn yields was shown to average 2765 kg ha^{-1}(Martin *et al*., 2005). The reasons for this variation can be attributed to interplant competition (Maddonni and Otegui, 2003), non-uniform stands (Nafzinger *et al*., 1991), sub-meter variability of nutrients (Raun *et al*., 1998; Solie *et al*., 1999), biotic and abiotic factors. Further, Raun *et al*. (2002) reported that optical sensors that collect NDVI data to refine N rates have been proven to increase NUE by 15%. They used in-season estimation of yield (INSEY) and a response index to predict yield in winter wheat and calculate N fertilizer rates on a 1 m^2 scale. Teal *et al*. (2006) accurately used days from planting and INSEY to predict maize grain yield.

In Ethiopia, where maize is grown, farmers often do not apply adequate amounts of fertilizer. Even when applied, the basal application, which is crucial from the production point of view, is missed. Not only the fertilizer dose but its management is also very important for increasing the productivity and fertilizer use efficiency. About 30 to 70% of the applied nitrogen may be lost as ammonia within 7 to 10 days after application. Improved management can substantially reduce these losses. The nitrogen use efficiency of urea, the most common source of nitrogen, is low. This is one of the important reasons for low yield, particularly in high rainfall and moisture stress areas of Ethiopia (Tolessa *et al*., 2002). Thus, an appropriate method of application needs to be propagated. Increasing efficiency of N fertilizer is a primary concern from both an agronomic and environmental standpoint and will help to strengthen the long-term sustainability of western part of maize production in the country. Hand held Green Seeker sensor is one of a N management tool that can improve NUE with significant increase in net profits for cereal and grain crops (Tolera *et al.*, 2015).

2.5.6 Nitrogen Fertilizer Side Dressing

In order to minimize N losses and increase NUE, many producers have adopted the practice of split applications, which involves applying N numerous times throughout the growing season and typically at lower rates, compared to methods in which the required N rate is applied at once prior to planting. The reduced rates of pre-plant N reduce the potential for large amounts of N loss. Jones (2013) suggested that in-season applications, often referred to as side-dress applications, supply a majority of the plant N requirement when the plant is actively taking up N and loss potential is subsequently minimized. Sidedress applications are effective at meeting corn N requirements and increasing NUE. Fox *et al*. (1986) reported increased NUE with a side-dress application when compared to other N applications when using ammonium nitrate or urea. Jung *et al*. (1972) observed similar results when a single side-dress application was applied in a window from week 5 to 8 after planting or from the V5 to V12 maize growth stage.

Regardless of why a producer may choose to apply side dress N, one problem is the limited window of time for making effective side-dress applications. Binder *et al*. (2000) suggested that side dressing must occur while plants are small enough to allow equipment access and before deficiency occurs. The optimal growth stage for side dressing maize depends on the nutrient status of the crop. When N is sufficient, the timing is less critical than maize that is highly N deficient. The authors further stated that the greater the N deficiency, the earlier a side dress N application is warranted, and if the deficiency is not corrected overall grain yields have been shown to decrease as much as 0.32% per day.

Calculating accurate side-dress rates to meet crop needs poses a problem to producers. Johnson (1991); Dahnke *et al*. (1988) stated that N application rates can be determined by the hinder capturing of aerial images (Shaver *et al*., 2011). As an alternative, the use of “active” crop sensors as a basis for in-season variable rate N applications has been proposed. Rising N prices and greater emphasis on environmental quality has led some producers to utilize in-season diagnostic tests to determine N rate that optimizes NUE and profitability. To accurately account for in-field N variability, variation must first be assessed, which can be expensive and labor intensive. To reduce time and manual labor for estimating field N availability and plant N needs some researchers have looked towards remote sensing.

Remote sensing has not been used in Ethiopian agriculture. In recent years, ground based sensors (Green seeker) was utilized to determine N needs. Tolera *et al*. (2014; 2015); Adis *et al.* (2015) reported that Green Seeker (Trimble, 2012) sensors can be used to predict in-season optimal N rates for quality protein maize varieties. Scharf *et al*. (2011) used the Green Seeker to compare N algorithm rates against producer-chosen N rates and reported that the sensor based rate recommendations reduced N application by 16 kg N ha^{-1} or 25% as compared to the producer calculated rates and in some years, increased grain yield. If Green Seeker prescribed N rates accurately depict crop N needs during early season growth, active sensors could reduce severe yield losses that occur with early season N deficiencies and permit fertilizer application equipment access which could potentially increase sensor adoption as an N management tool (Scharf *et al*., 2011).

2.5.7 Sensor Based Technology in Nitrogen Management

Precision farming has been a major research focus of agronomists for over a decade (Shanahan *et al.*, 2008). Sripada (2005) stated that predictions of crop N requirements and yield are derived from the product of field area and estimates of fertilizer rates based on tissue N, available soil N, or yield per unit area. When compared to the traditional methods of soil and tissue sampling, collecting such information on a large scale can be achieved more economically using remote sensing techniques. The information collected by this technology can be used as an aid in decision making to target crop and soil inputs according to the requirements of the field which should result in optimal profitability and protection of the environment. There are available a few brands of crop sensors for growers, each one with its own construction characteristics like internal batteries, GPS antenna, data logger and log frequency (Povh and Anjos, 2014).

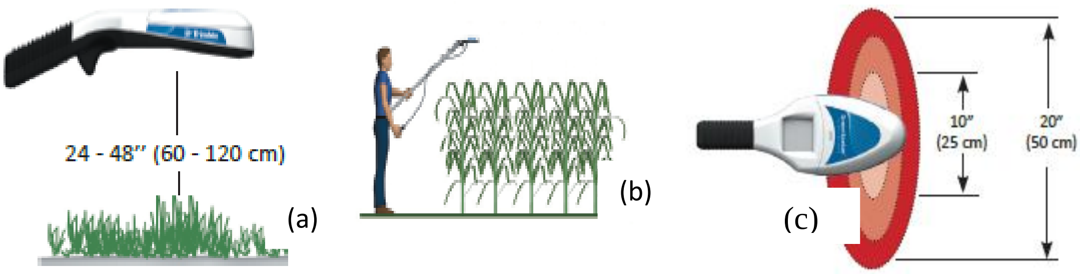
A prominent example of crop remote sensing technology is the Green Seeker® integrated optical sensor (Fig. 5) that used to measure plant biomass and displays as Normalized Difference Vegetative Index (NDVI). It was developed at Oklahoma State University, USA and licensed to N Tech Industries Inc. in 2001 (Trimble, 2012). When upon pulling the trigger, the sensor turns on and emits brief bursts of red and infrared light, and then measures the amount of each that is reflected back. Green plants absorb most of the red light and reflect most of the infrared light.

The sensor should held 24-48" (60-120 cm) above the crop, but the sensors field of view is an oval (Fig. 6). The Remote Switch Kit allows the users to position the crop sensor at a sufficient height over taller crop canopies. Typical applications for using this tool include sensing and agronomic research, biomass measurements and plant canopy variations, nutrient response, yield potential, pest and disease impacts. This allows getting real time readings for grain crops, vegetables, sugar cane and many others (Trimble, 2012).

Handheld Green Seeker can be used to make non-subjective decisions regarding the amount of fertilizer to be applied to a crop, resulting in a more efficient use of fertilizer and a benefit to both a farmer's bottom line and the environment. It uses an active light source (light emitted from the sensor) to measure spectral reflectance from crop canopy to calculate NDVI for determination of N dose by comparing it to a nitrogen rich strip within

Source: Trimble (2012)

Figure 5. Typical appearance and parts of Green Seeker handheld crop sensor (A= LCD display, B= Battery access panel, C= Wrist strap attachment loop, D= Trigger, E= Micro USB port for charging, F= Remote switch and G String attachment loop).



Source: Trimble (2012)

Figure 6. Positioning or distance from the crop canopy to sensor(a), extension arm (b) and size and shape field of view (c) of handheld Green Seeker crop sensor

the field (Johnson *et al*., 2002). The fraction of emitted light in the sensed area is reflected to the sensor and is measured by the device (Rouse *et al*., 1973).

The normalized difference vegetation index is the difference between the radiance in the NIR and R bands divided by the sum of the radiances in the NIR and the R bands, where NDVI = (NIR- R)/(NIR + R). It has been the most widely used vegetation index (Kaufman and Tanre, 1992). The NDVI value ranges between 0.00 and 0.99 (Trimble, 2012). There have been numerous studies that showed high correlations between certain vegetation indices developed from spectral observations and plant stand parameters such as plant height, percent ground cover by vegetation, and plant population (Raun *et al*., 2005). In order to evaluate the impact of vegetation cover on sensor readings, Lukina *et al*. (1999) evaluated percent vegetation coverage at different wheat growth stages and row spacing. Their work demonstrated a high correlation (0.80-0.97) between percent vegetation coverage and NDVI measurements. The NDVI has been considered as an indirect measure of crop yield, including that of wheat (Colwell *et al*., 1977; Tucker *et al*., 1980; Pinter *et al*., 1981).

Data presented by Oklahoma State University researchers indicate a benefit of US $ 40/ha to US $ 95/ha by economizing N application in wheat (Johnson *et al.*, 2002). Green Seeker optical sensor technology enables researchers to measure, in real time, a crop's nitrogen levels and variably apply the "prescribed" nitrogen requirements. Li *et al.* (2009) and Zillmann *et al.* (2006) reported increased nitrogen use efficiency by the use of spectral radiance, including the NDVI. The NDVI measurements can be used as an objective parameter for crop performance judgment, both in time and space, giving more dynamic and immediate information than does the static end-of season yield results (Govaerts, 2007). Li *et al.* (2009); Tubaña *et al.* (2008) also showed the Green Seeker sensor to be a N management tool that can improve NUE with significant increase in net profits for cereal and grain crops. Scharf and Lory (2002) used relative green from aerial color images to predict optimum sidedress N in maize at the V6-V7 stage. Sripada *et al*. (2005) developed an algorithm to estimate the economic optimum N rate at near tasselling based on the Green difference vegetative index (RGDVI) calculated from aerial color infrared (CIR) photographs. These and many other studies show that sensors could be used to predict yield potential and N requirements.

Hence, the benefits of using the optical sensor system in agriculture, reaffirming that the development of this technology can be very useful in detecting plant N status and making fertilizer recommendations. This technology which helps producers better manage N fertilizer and to achieve maximum production with the minimal inputs is for most importance. Better N management not only helps producers get more value for their N investment, but also reduces the risk of environmental pollution. Handheld Green Seeker units are already in use in Asia, Australia, Europe, USA and Latin America. However, it is the latest addition to the list of crops sensors in Ethiopian agriculture.

Recently, CIMMYT-Ethiopia started program on nitrogen management using green seeker sensor in maize with the collaboration of national and regional agricultural research institute. Our preliminary observations of 2014/15 on NDVI in relation to canopy development and crop growth in hybrid of BHQPY545 QPM are very encouraging and envisage a potential scope of Green Seeker optical sensor for monitoring crop growth in order to validating timing and dose of N application for maximizing maize production and productivity of quality protein maize.

There are a number of factors that can influence the apparent reflectance from a maize canopy in the near-infrared (NIR) and visible regions of the electromagnetic spectrum. Measurements in the field can be affected by the sensor positioning, like the distance from the crop, dependence of a light source, the presence of dew over the leaves and also because of factors that can stress the plants (Povh and Anjos, 2014). The light source classifies the sensors in active and passive sensors. The passive sensors are dependent of sunlight, not working at night or might show different readings when there are clouds or shadows. Povh and Anjos (2014) studying an experiment conducted along the day, collecting NDVI values at the same spot but in different times of the day showed that the presence of dew on the leaves reduced the NDVI values of 12% for Green Seeker and 27% for Crop Circle, from the first (7:30 am) to the last reading (11:30 am). The presence of dew is just because the presence of water over the leaves can change the reflectance in both visible and near infrared. There is also a limitation of the distance from the target to the sensor, because if it is too close the sensor may not capture the reflectance, and if it is too far the data may have noise signals (Povh and Anjos, 2014).

The spectral reflectance of a crop canopy is a combination of the reflectance spectra of plant and soil components. Spectral reflectance in the red (R) region (600-700 nm) of the electromagnetic spectrum is inversely related to the *in-situ* chlorophyll density, while spectral reflectance in the NIR (750-1350 nm) is directly related to the green leaf density (Gates *et al.,* 1965). Further, it has been reported that vegetation under stress shows a decrease in reflectance in the NIR bands, a reduced R absorption in the chlorophyll active band (680 nm), and a consequent blue (B) shift on the R edge (Blackmer *et al.,* 1996). Non-green components also contribute to the canopy spectral reflectance, and vegetation indices have been reported to vary due to soil background (Huete, 1989).

Because of the number of factors that can influence crop spectral characteristics, Blackmer and Schepers (1995) developed a N sufficiency index (NSI) relative to chlorophyll meter readings from a non-N-limited area to compare N status across fields and for fertigation in maize in the Great Plains. Similarly, Scharf and Lory (2002) used relative G to predict optimum sidedress N in corn at the V6-V7 stage. In a similar manner, the remote sensing based in-season N requirement prediction model for corn developed by Sripada *et al*. (2005) used within-field references in the form of high-N strips.

Based on promising results of nitrogen management using Green seeker sensors, Adis *et al.* (2015); Tolera *et al.* (2014; 2015), also indicated the need for validation of predicted in-season nitrogen fertilizer rates and recommend side dressing of N for quality protein maize varieties. Similarly, from a farmer’s perspective, the adoption of a remote sensing technique to predict in-season N requirements in a maize production system would depend in part on the accurate prediction of that requirement.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted at Bako Agricultural Research Center, West Showa Zone of Oromia Regional State, Ethiopia (Table 7), in 2016 cropping season. The area lies at an altitude of 1650 m.a.s.l. and is situated at 9^{o} 6' N latitude and 37^{o} 09' E longitude. Mean annual rainfall is 1239 mm with unimodal distribution (MBARC, 2015). The experimental area is characterized by warm and humid climate with mean minimum, mean maximum and average air temperatures of 13.2, 28 and 21^{o}c, respectively (WWW.IQQO.ORG). The soil type is brown clay loam Nitisols (Mesfin, 1998).

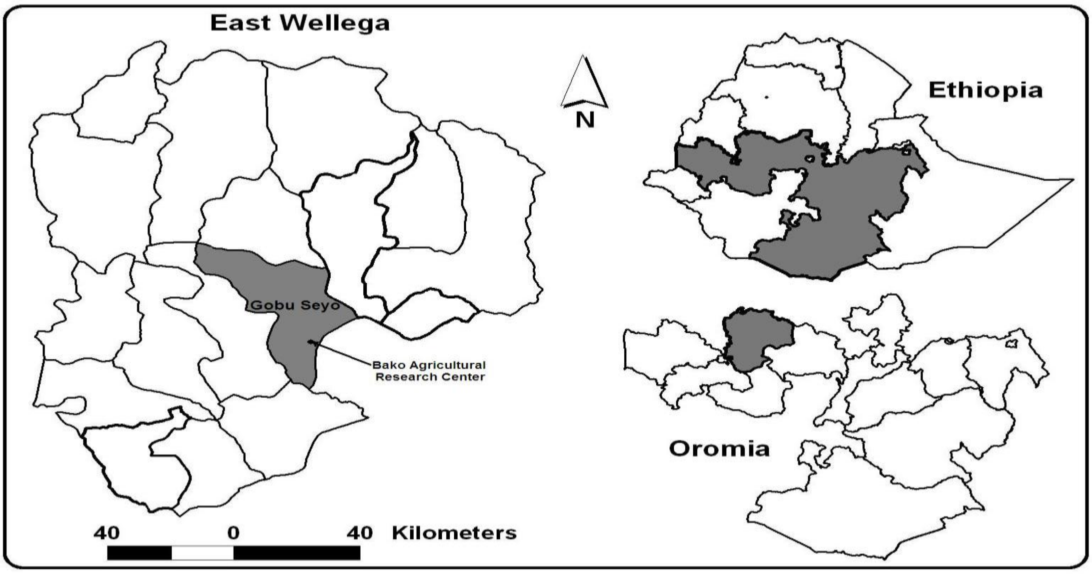


Figure 7. Study district in East Wallaga Zone of Oromia, Ethiopia

3.2 Experimental Materials

3.2.1 Variety

The QPM variety BHQPY545 which is a single cross hybrid released by Bako National Maize Research Center in 2008 was used for the study as a source of seed. The cultivar is well adapted to mid-altitude areas of Ethiopia (1000-1800 m.a.s.l) and rainfall of 500-1000 mm. It needs 144 days to maturity, having a yellow kernel with straight kernel row arrangement and resistance to rust and blight. It performs better if planted during end of May to mid-June. It has yield potential ranges from 8.0-9.5 t ha^{-1} at research field and 5.5-6.5t ha^{-1} at farmers field (Adfris *et al*, 2015).

3.3.2 Fertilizer

Nitrogen fertilizer in the form of urea (46 kg N ha^{-1}) was applied at different rates and time as constituted in the treatments, while the recommended rate of phosphorus fertilizer (46 kg P_2O_5 ha^{-1}) in the form of Triple Super Phosphate (TSP) was applied uniformly to all plots at the time of planting.

3.3 Experimental Design and Treatments

The experiment was laid out 3x4 factorial in randomized complete block design with three replications on a plot area of 5.1m x 4.5m (22.95 m^2). Each plot consisting of six rows and the distance between adjacent plots and blocks kept at 1.0 and 1.5 m apart, respectively. Three rates of nitrogen fertilizer (0, 25 and 50 N kg ha^{-1}) and four rates of N (19, 38, 56 and 75 kg ha^{-1}) for side dressing were used as treatments during the experiment. A nitrogen rate of 75 kg ha^{-1} was used based on nitrogen calibration results for calculating the estimated nitrogen level. The 0, 25 and 50 kg ha^{-1} nitrogen rates were applied at time of planting and the estimated four rates of nitrogen (19, 38, 56 & 75 kg ha^{-1}) were applied at 35 days after planting. Seeds were planted with inter-rows spacing of 75 cm apart and intra-row spacing of 30 cm, two seeds per hill were sown to ensure emergence and a good stand of the crop. However, to obtain the required plant density, the seedlings were thinned to one plant per hill two weeks after emergence. All other agronomic management practices were applied uniformly as per the recommendation for maize in the area.

Table 3. Descriptions of the treatment combinations of nitrogen fertilizer application rates used in the study at Bako, Western Ethiopia Descriptions

Treatment code	Treatments	
	Nitrogen rates at planting (kg ha^{-1})	N rates for Side Dressing (kg ha^{-1})
1	0	19
2	0	38
3	0	56
4	0	75
5	25	19
6	25	38
7	25	56
8	25	75
9	50	19
10	50	38
11	50	56
12	50	75

3.4 Agronomic practice

All field activities were carried out following standard production practices. Planting was done on June 8, 2016 by placing the seeds in hand made furrows at the inter and intra-row spacing of 75 cm and 30 cm, respectively. Phosphorus fertilizers in the form of triple super phosphate (TSP) at the recommended rate of 46 kg P_2O_5 ha^{-1} was equally applied to all plots by banding at the time of planting. For the N fertilizer application, urea was applied at the specified rates and timing by banding at planting approximately 2-3 cm distance from the seed and immediately covered with soil, and by top dressing during the growth of the plants.

Weeds were managed by hand weeding after weed emergence. Late-emerging weeds were also removed by hoeing to avoid interference with the maize plants for the N applied. Stand count at emergence to see the uniformity of the plant stand and NDVI measurement using pocket handheld sensor was taken from the central four rows of net plot area at vegetative stage four (V4) and vegetative stage six (V6). Finally, maize plants in the central four rows (net plot area) were harvested on December 05, 2016.

3.5. Data Collected

3.5.1 Normalized Difference Vegetative Index reading and calculating of In-season estimation of yield

Normalized difference vegetative index (NDVI) values were taken from the central four rows of net plot area using "pocket" hand-held NDVI sensor at vegetative stage of leaf four (V4), leaf six (V6) and leaf eight (V8) of the QPM. Thus, In-season estimation of yield (INSEY) were computed for optimum grain yield of maize. INSEY vs. grain yield relationship were established as: INSEY= NDVI/GDD, where, GDD is the number of Growing Degree Days greater than zero from seeding (or seed emergence) to sensing. The INSEY provides an estimate of daily biomass production or growth rate (Raun *et al*., 2005) and is therefore an important determinant of final grain yield. Growing Degree Day (GDD) = ((daily maximum T + daily minimum T) ÷ 2)-base temperature for maize. The base temperature for maize is $10^0{}_C$.

3.5.2 Phenological and growth parameters

Leaf area index (LAI): Leaf area at silking was determined by multiplying average leaf length and width, and adjusted by a correction factor of 0.75 ((average leaf length x leaf width) x 0.75). Leaf area index was then calculated by dividing leaf area per sampled ground cove area.

Plant height: It was measured as the height from the soil surface to the base of the tassel of five randomly taken plants from the net plot area.

3.5.3. Yield and yield components

Thousand kernels weight (g): It was determined from 1000 randomly taken kernel from each plot and weighed using sensitive balance.

Ear weight: Ear weight/plot was measured using electronic balance during harvesting.

Grain yield per plot= (ear weight x 0.81) x ((100-M.C) ÷ (100-12.5)) Where, Era weight= Actual ear weight measured (kg per plot) at harvesting, M.C= Actual grain moisture content at harvesting, 12.5= standard moisture content for maize and 0.81= correction factor.

Grain yield (kg ha^{-1}): was determined from ear weight and then adjusted to 12.5% moisture and converted to per hectare basis.

Above Ground Biomass Yield (kg ha^{-1}): five randomly taken plants from the net plot area at harvesting were taken, weighed and converted to per hectare basis.

Harvest index (HI): It was calculated as the ratio of grain yield to total aboveground biomass yield as follows:

HI= GY (kg ha^{-1}) ÷ DB (Kg ha^{-1}) Where, HI= harvest index, GY=Grain yield (at 12.5% moisture base) and DB= above ground dry biomass yield (Stover +grain yield).

3.6 Statistical analysis

The collected data were analyzed using Gen Stat 15th Edition software packages. Mean separation was done using Duncan's multiple range tests at 5 % probability level (Duncan, 1955). Pearson's correlation and regression analysis were performed to observe association and relationship between different variables as affected by different levels of nitrogen fertilizer applications.

3.7 Economic Analysis

To identify the economic optimum N fertilizer rate, economic analysis was done using the CIMMYT partial budget analysis (CIMMYT, 1988). To estimate economic parameters, maize grain yield was valued at an average open market price of ETB 7.00 kg^{-1} for the last five years at Bako. The yield was adjusted by 10% to reflect actual production environments (CIMMYT, 1988). The seed cost of quality protein maize was ETB 51.36 kg^{-1}. Urea was valued at the official prices of ETB 1120.00 per 100 kg. The Gross benefit was calculated as average adjusted grain yield (kg ha^{-1}) multiplied by field price that farmers receive for the sale of the crop (7.00 ETB kg^{-1}). Total variable cost (TVC) as the sum of all cost that was variable or specific to a treatment. Net benefit was calculated by subtracting total variable cost from the gross benefit. Then treatments were arranged in an increasing TVC order and dominance analysis was performed to exclude dominated treatments from the marginal rate of return (MRR) analysis. A treatment is said to be dominated if it has a higher TVC than the treatment which has lower TVC next to it but having a lower net benefit. A treatment which is non-dominated and having a MRR of greater or equal to 50% and the highest net benefit is said to be economically profitable.

4. RESULTS AND DISCUSSION

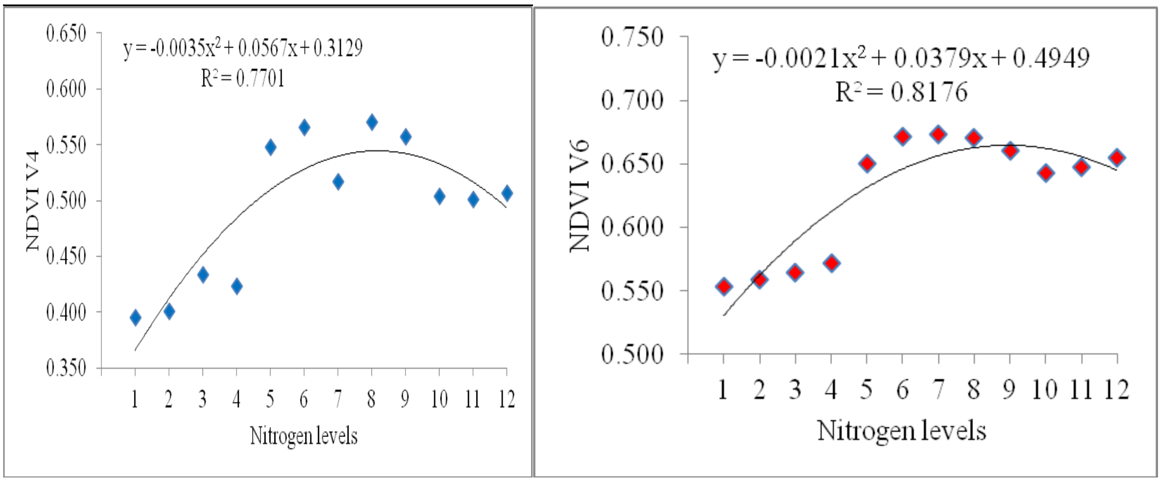
4.1 Interaction effects

The analysis of variance showed that the interaction effect between the application of N fertilizer rates at planting and side dressing was significant at 1% probability level for grain yield, above ground dry biomass, leaf area (LA), harvest index (HI) and 1000 grain weight of quality protein maize (Appendix table 1). There was also significant difference between the application of N fertilizer rates at planting and side dressing on leaf area index (LAI) at 5% probability level. Application of N fertilizer at planting showed a highly significant effect on plant height, LA, LAI, grain yield, dry biomass, HI and 1000 grain weight ($P<0.01$). Whereas, application of N fertilizer rates as side dressing showed a highly significant effect for certain variables studied like LA, grain yield and dry biomass ($P<0.01$). But application of N fertilizer as side dressing showed a significant effect on LAI, HI and 1000 grain weight ($P<0.05$). However, the interaction and the main effect of N application as side dressing showed a non significant effect on plant height (Appendix 1). Normalized difference vegetative index (NDVI) with hand-held sensor at node initiation (V4) growth stage of maize was significantly ($P<0.01$) affected by application of N rates at planting and side dressing (Appendix table 2).

4.2 Normalized Difference Vegetative Index (NDVI)

4.2.1 The NDVI versus N fertilizer rate and side dressing

Significantly higher NDVI value at V4 was recorded from application of 25 kg N ha^{-1} at planting with 75 kg N ha^{-1} side dressing and it shows a consistent increase in NDVI value as N rate and side dressing increased from 0/19 kg N ha^{-1} up to 25/75 kg N ha^{-1} (Table 5 and Fig. 8).



1= 0/19, 2= 0/38, 3= 0/56, 4= 0/75, 5= 25/19, 6= 25/38, 7= 25/56, 8= 25/75, 9= 50/19, 10= 50/38, 11= 50/56, 12= 50/75 kg ha^{-1} nitrogen fertilizers at planting/side dressing.

Figure 7. Nitrogen level Vs. Normalized Difference Vegetative index of maize at V4 and V6 growth stage in 2016 cropping season at Bako, Western Ethiopia

The graphs of regression analysis indicate a strong relationship between applied N fertilizers and NDVI readings at V4 and V6 growth stages of QPM (Fig. 8). Strong relationship between applied N fertilizer and NDVI readings were observed (R^2= 0.77 and 0.82) at V4 and node elongation (V6) growth stages correspondingly, resulted in a good relationship between applied N fertilizer and NDVI readings. As the N level increase NDVI readings from the NDVI sensor become higher at V4 and V6.

The results of NDVI shows that readings become greater while growth continues after V4, but it was small at the binging. This space cover failure of the canopy might be resulted in the lower correlation at young vegetative stages (V4) (Table 6). Correlation was possible low due to the initial growth stage/failure of canopy cover the space) and lack of early N stress. Starting at V5 and later vegetative stages, the correlation improved most likely due to a more similar canopy. This results in agreement with the findings of Raun *et al*. (2001).

The NDVI is successful in predicting photosynthetic activity because this vegetation index includes both near infrared and red light. Plant photosynthetic activity is determined by chlorophyll content and activity. Many literatures stated increment in N level enhance Spectral vegetation indices such as the NDVI which have been correlation, shown to be useful for indirectly obtaining information such as photosynthetic efficiency, productivity potential, and potential yield (Baez-Gonzalez *et al*.,2002).

4.2.2 Relationship between NDVI and grain yield

There were strong curvilinear relationships between the NDVI reading and grain yield of quality protein maize (Fig. 9). This confirms that hand held NDVI sensor is the right indicator of crop health, unstressed and which can provide maximum yield. Besides this, it shows that the hand held sensor is one of the best instruments in precision agriculture to manage nutrients for economic return as well as to reduce environmental pollution as a result of poor N fertilizer management. Moges, (2004); and Lukina (2001) found NDVI readings taken at these same stages were positively correlated with final grain yield. This result also agrees with Tolera *et al.* (2014; 2015); and Adis *et al*. (2015) who reported strong relationship between NDVI and grain yield of quality protein maize. In contrary, Fernando (2008) reported that linear relationships between variation in relative grain yield and relative values for two sensor-determined vegetation indices.

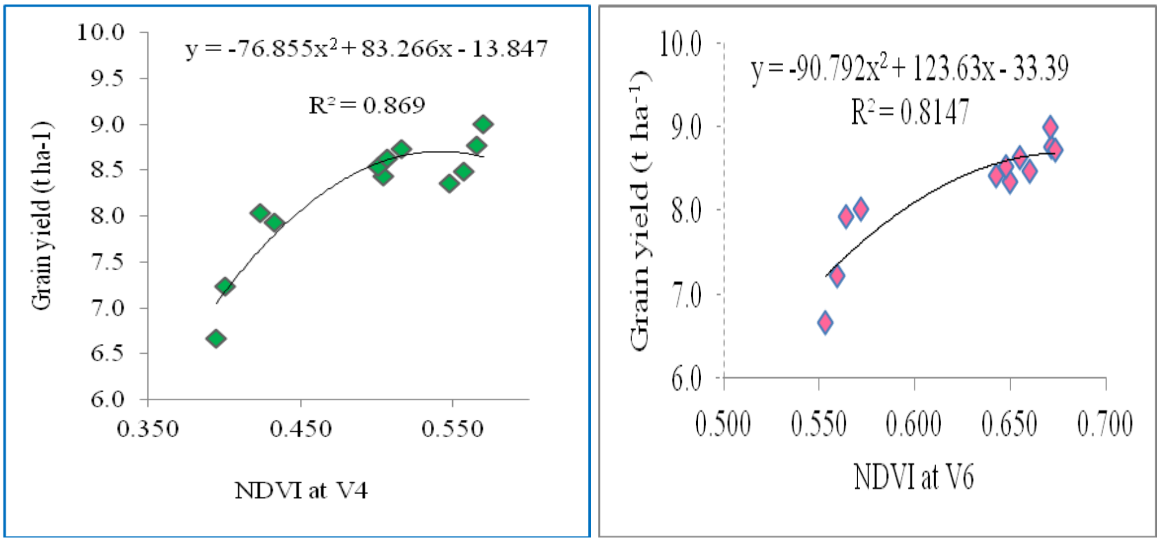


Figure 8. Grain yield of maize Vs. NDVI at V4 and V6 at Bako, 2016 cropping season

4.3 In-Season Estimation of Yield (INSEY)

4.3.1 Relationship between INSEY and application of N fertilization

There was a strong relationship between the INSEY and application of N fertilizer at V4 (R^2= 0.75), at V6 (R^2= 0.79) and at V8 (R^2= 0.80) (Fig. 10 and 11). It indicates, the INSEY value increases as the N fertilizer levels increase steadily from 25 kg ha^{-1} towards 63 Kg N ha^{-1} (N at planting and side dressing), this is due to that N fertilizer have great role in plant growth and development, and also in the development of chlorophyll content of the leaf (Adis *et al*., 2015). Since nitrogen gives the green color to the leaf appearance thus contributes to the increment in NDVI reading values finally to achieve higher in-season yield estimate. There was significant difference between the INSEY with application of N fertilizer rate at V4 growth stage of maize. The higher INSEY value was recorded from the application of 100 kg N ha^{-1} (25 at planting and 75 kg ha^{-1} N applied as side dressing) at V4 (Table 5). Similar result was reported by Adis *et al.* (2015). However, at V4 growth stages the lowest value was recorded from the minimum rate of nitrogen fertilizer application, 0 kg N ha^{-1} rate at plating with 19 kg N ha^{-1} applied as side dressing. This result also agrees with Adis *et al.* (2015).

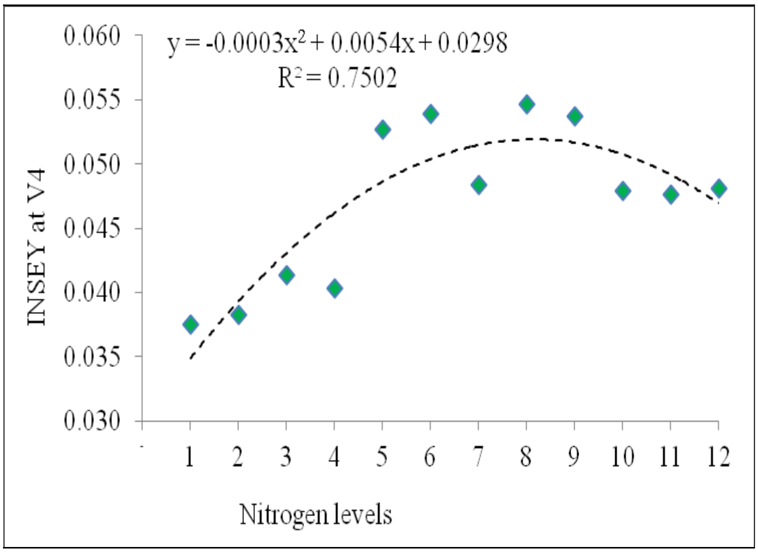


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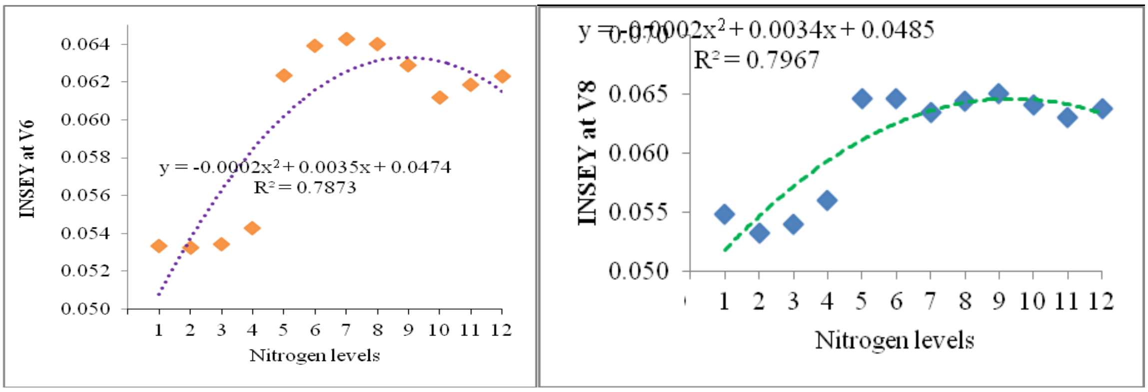
Figure 9. Application nitrogen rates Vs. INSEY at V4 growth stage of quality protein maize, during 2016 cropping season, at Bako, Western Ethiopia



1= 0/19, 2= 0/38, 3= 0/56, 4= 0/75, 5= 25/19, 6= 25/38, 7= 25/56, 8= 25/75, 9= 50/19, 10= 50/38, 11= 50/56, 12= 50/75 kg ha^{-1} nitrogen fertilizers at planting/side dressing

Figure 10. Application of N rates Vs. INSEY at V6 and V8 growth stage of QPM, during 2016 cropping season, at Bako, Western Ethiopia

4.3.2 Relationship between INSEY and grain yield

There was significant ($P<0.01$) difference among INSEY values was observed in response to applied nitrogen rates at V4 growth stage of maize (Appendix table 2). A Strong relationship between INSEY and the harvested grain yields of maize was observed with R^2= 0.87, 0.76 and 0.71 at V4, V6 and V8 growth stages respectively (Figs. 12 and 13). This indicates predicting grain yield with INSEY for QPM. This results in agreement with findings of Adis *et al.* (2015); and Tolera *et al.* (2014; 2015) on quality protein maize varieties. Stevens (2014) also reported that INSEY was found to be correlated to grain yield. A similar report, a strong relationship existed between wheat grain yield and INSEY, with a coefficient of determination of 83% (Raun *et al*., 2001).

Measured grain yield was increased up to 100 kg ha^{-1} N fertilizer applied at V4 (Table 5) in a similar pattern the INSEY increase, a gradually result of both parameters decline, implying that greater NUE is achieved at 100 kg ha^{-1} N. The smallest result of both, grain yield, and INSEY was recorded from the lowest N fertilizer treatment at V4, V6 and V8 of growth stages of maize (Table 5). However, non-significant difference among applied N rates at V6 and V8 (Appendix table 2), this might be due to the canopy closure as growth continues, and create higher in the NDVI sensor reading values. Similar result was reported by Adis *et al.* (2015); and Vina *et al.* (2004) due to canopy closure influence on the sensor field of view, the later NDVI readings were unable to distinguish variation, similar to research findings for other remote sensing techniques measuring NDVI.

This method of N management for maize production provides an opportunity for the producer to apply only the needed N fertilizer on their farms, thereby maximizing their production, reducing their cost of production and reducing the incidence of environmental pollution.

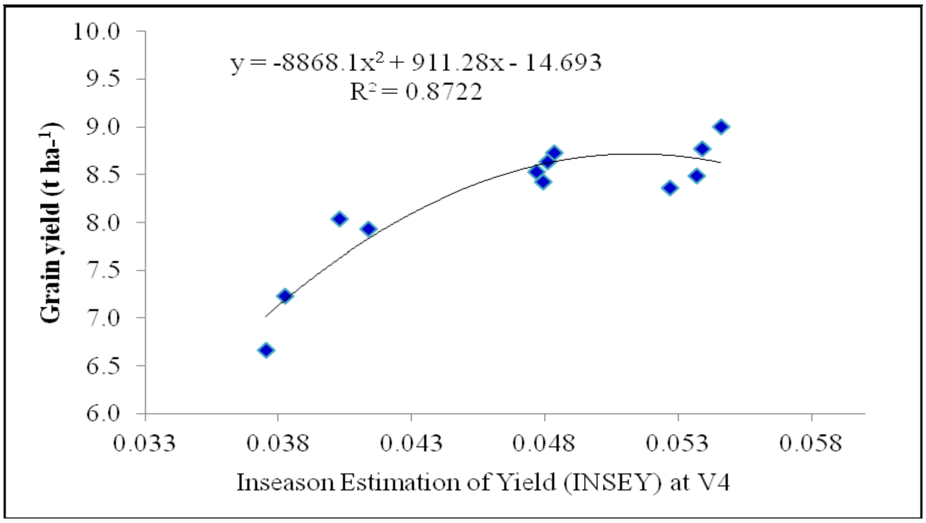
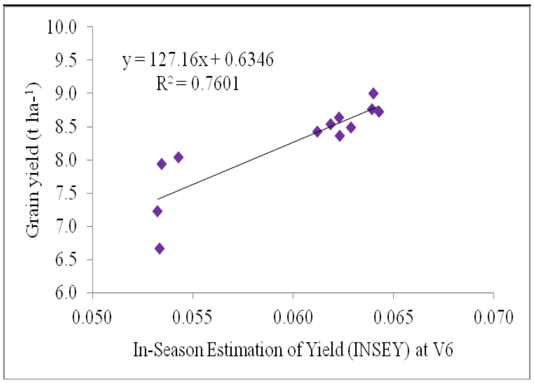


Figure 11. Grain yield Vs. INSEY at V4 growth stage of quality protein maize, 2016 cropping season, at Bako, Western Ethiopia



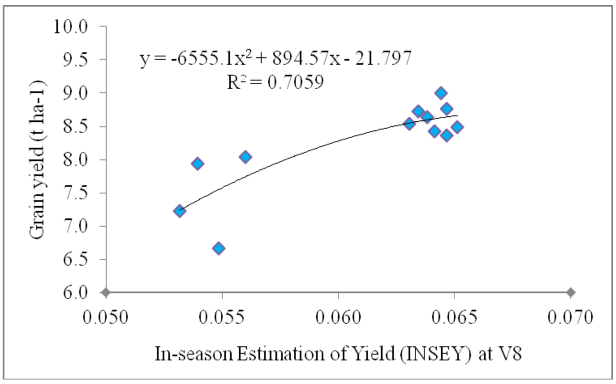


Figure 12. Grain yield Vs. INSEY at V6 and V8 growth stage of quality protein maize, during 2016 main cropping season at Bako

4.4 Yield components of Maize

Significantly ($P<0.05$) higher increase of mean yield components of quality protein maize was obtained up to 25 kg N ha^{-1} rate with 75 kg N ha^{-1} side dressing then decrease (Table 4). Increasing N rate from 0 to 50 kg ha^{-1}and side dressing N from 19 to 75 kg ha^{-1} increased significantly LA and LAI of QPM variety but 50 kg ha^{-1} N rate combined with side dressing N fertilizer shows decreasing for dry biomass, HI and 1000 kernel weight. Higher LA (5936 cm^2), LAI (2.64) and dry biomass (25.4 t ha^{-1}) were obtained from the application of 25 kg N ha^{-1} at planting with 75 kg N ha^{-1} side dressing, where as higher 1000 grain weight (341 g) of QPM was recorded from application of 25 kg N ha^{-1} at planting with 19 kg N ha^{-1} N side dressing (Table 4). The lower LA (5078 cm^2) and LAI (2.21) of QPM were obtained from 0 kg ha^{-1} N rate at planting with 38 kg N ha^{-1} side dressing, whereas lower 1000 kernel weight with 314 g and dry biomass with 18.3 t ha^{-1} of quality protein maize were obtained from use of 0 kg N ha^{-1} with 19 kg N ha^{-1} side dressing nitrogen application (Table 4). While the lower HI with 35.5% was recorded from use of 50/56 kg N ha^{-1} applied at planting and side dressing N levels.

Table 4. Effects of nitrogen rate applied at planting and side dressing on data collected for quality protein maize variety at Bako, Western Ethiopia

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

NL= Nitrogen levels, SD= nitrogen rate for side dressing, LAI= Leaf area index, DB= Above ground dry biomass, HI= Harvest index and TKW= 1000 kernel weight.

4.5 Grain Yield of Maize

Mean grain yield of quality protein maize was significantly ($P<0.05$) increased with applied nitrogen fertilizer rates (Fig. 14). Nitrogen application rates and side dressing produced significantly higher increase up to 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} side dressed N applied and beyond that small increase of grain yield (Table 5 and Fig. 14). The result agrees with findings of Tolera *et al.* (2014; 2015); and Adis *et al.* (2015). Similarly, Torbert *et al.* (2001) reported that grain yield was increased with increasing nitrogen fertilizer up to 168 kg ha^{-1} in wet years. Therefore, application of 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} side dressed was agronomically recommended for quality protein maize varieties at Bako.

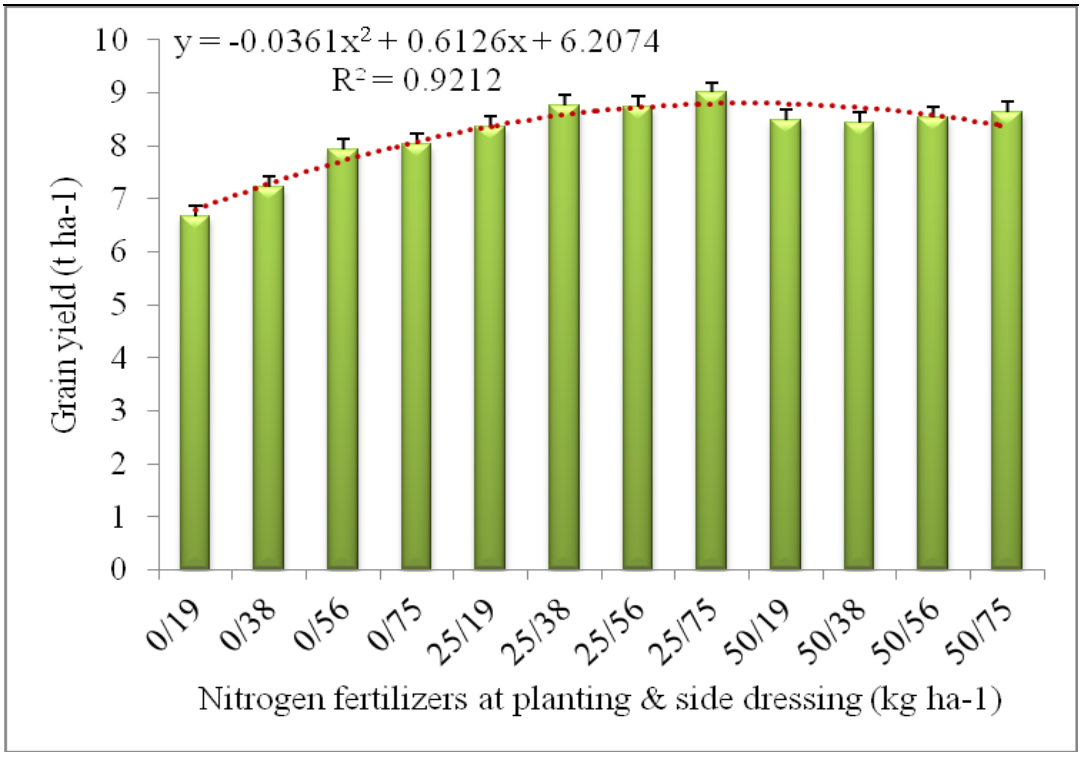


Figure 13. Grain yield vs. application of nitrogen fertilizer for quality protein maize during 2016 cropping season, at Bako, Western Ethiopia

Table 5. NDVI reading, INSEY and grain yield of QPM at Bako, Western Ethiopia.

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

4.6 Interrelationships between growth phenology and yield components of maize

Application N fertilizer was significantly positively associated with all growth phenology, yield and yield components of maize except 1000 seed weight and HI which were non-significant and significant negatively associations (Table 6). It indicates that, the growth phenology, yield and yield components of QPM will be increased. Side dressing of N fertilizer with yield components of maize showed non-significant association except for grain yield (Table 6). Significantly higher positive association (0.68, 0.71 and 0.73) were obtained between application N and NDVI of QPM at V4, V6 and V8 growth stage, it means that, if the application of N rates is increased, NDVI of yield at V4, V6 and V8 growth stage of maize will be increased. There is also higher positive correlation (0. 67, 0.77 and 0.74) between application N rates and INSEY of QPM at V4, V6 and V8 growth stage, it means that, if the application of N rates is further, INSEY of yield at V4, V6 and V8 growth stage of maize will be increased further. Additionally, significantly positive association (0.59, 0.48, 0.60, 0.77 and 0.76) were obtained between application N and plant height, dry biomass, grain yield, LA and LAI of QPM respectively, it means that, if the application of N rates is further, these yield parameters and yield of QPM will be increased. However, application of N fertilizer was negatively associated with HI of maize (-0.34).

Plant height had positive and significant correlation with above ground dry biomass and calculated INSEY at V8, NDVI at V4 and V6 (0.66, 0.57 and 0.65). This shows as the plant height is increases, above ground dry biomass and calculated INSEY at V8, and NDVI at V4 and V6 of QPM will also increase. The NDVI reading and calculated INSEY at V4, and LAI and NSEY at V6 growth stage of maize 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 of QPM. The NDVI at V4 with INSEY at V4 & V6 (0.98 and 0.93) and NDVI at V6 with INSEY at V4 and V6 growth stage (0.86 and 0.91) have higher positive correlation. This showed that the higher the NDVI reading the higher will be the INSEY yield and *vise versa*. Dry biomass of quality protein maize was positively associated with NDVI at V4 and LA, and reading NDVI and calculated INSEY at V8 (0.61 and 0.68). This may be attributed to the fact that increased dry biomass might have directly increased NDVI at V4, leaf area, NDVI and INSEY at V8. There is also significantly positive correlation coefficient between dry biomass and grain yield (0.9). This showed the higher biomass, the higher will be grain yield of maize.

The NDVI has been correlated to plant physiological parameters, maize grain yield and biomass production. This result agrees with findings of Tolera *et al. (2015)*; and Adis *et al*. (2015) on calibration of N fertilizer for QPM. Govaerts (2007) also found the highest correlation between NDVI and final maize yield during the reproductive phase. Therefore, there was a strong relationship between NDVI, INSEY and grain yield of quality protein maize.

Table 6. Relationship between various phenological growth, yield and yield components of quality protein maize under different N level of application at Bako in 2016 cropping season, Western Ethiopia

	N	SD	PH	DB	GY	TW	HI	LA	LAI	NDF	NDS	NDE	INF	INS	INE
N		0.000	0.59**	0.48*	0.597**	0.063	-0.357*	0.774**	0.762**	0.681**	0.714**	0.731**	0.668**	0.768**	0.737**
SD			0.09	0.31	0.370*	0.014	0.051	0.192	0.229	-0.012	0.071	-0.006	-0.032	0.057	-0.016
PH				0.66**	0.700**	0.178	-0.454**	0.535**	0.483**	0.572**	0.647**	0.638**	0.586**	0.555**	0.656**
DB					0.897**	0.428*	-0.347*	0.613**	0.580**	0.611**	0.688**	0.679**	0.641**	0.606**	0.682**
GY						0.415*	-0.341*	0.765**	0.747**	0.777**	0.794**	0.730**	0.775**	0.752**	0.729**
TW							0.144	0.175	0.196	0.363*	0.400*	0.358*	0.388*	0.387*	0.350*
HI								-0.324*	-0.251	-0.198	-0.365*	-0.330*	-0.180	-0.294	-0.340*
LA									0.960**	0.787**	0.777**	0.707**	0.754**	0.834**	0.704**
LAI										0.778**	0.766**	0.701**	0.756**	0.843**	0.698**
NDF											0.873**	0.829**	0.984**	0.927**	0.830**
NDS												0.875**	0.861**	0.910**	0.872**
NDE													0.851**	0.845**	0.998**
INF														0.905**	0.856**
INS															0.844**
INE															

N= Nitrogen rate applied at planting, SD= Nitrogen applied as side dressing, PH= Plant height, DB= Above ground dry biomass, GY= grain yield, TW= thousand seed weight, HI= Harvest index, LA= Leaf area, LAI= Leaf area index, NDF= Normalized difference vegetative index at V4, NDS= Normalized difference vegetative index at V6, 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.

5. EFFECTS OF NITROGEN RATE APPLICATION AT PLANTING AND SIDE DRESSING ON ECONOMIC FEASIBILITY OF QUALITY PROTEIN MAIZE PRODUCTION

The results of economic analysis for integrated nutrient management are indicated in (Table 7). The highest net benefit ETB 53,590 ha^{-1} with an acceptable marginal rate of return (MRR) of 380 % and value to cost ration of ETB 29 per unit of investment was obtained from application of 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} side dressing applied N fertilizers, which implies a very high increase in farmers' income with a simple improvement in crop managements. The second higher net benefit ETB 51,590 ha^{-1} and MRR 363% with value to cost ration of ETB 39 per unit of investment of QPM was achieved from application of 25 kg N ha^{-1} at planting and 19 kg N ha^{-1} side dressing. The minimum net benefit was obtained from the use of 0/19 kg ha^{-1} N fertilizer application. The values to cost ratio was ranged from ETB 14 to 68 per unit of investment was for 50/75 and 0/19 kg N ha^{-1} application at planting and side dressing for QPM. Therefore, application of 25/38 kg N ha^{-1} at planting and side dressing at knee height was economically feasible for maize production and recommended for quality protein maize.

Table 7. Partial budget analysis for nitrogen fertilizer rates applied at planting and side dressing for quality protein maize at Bako, Western Ethiopia

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

NL= nitrogen levels, Av.GY= Average grain yield, Adj.GY= Adjusted grain yield to 10%, TVC= Total Variable Costs, D= Dominance Analysis, MRR= Marginal Rate of Return.

6. SUMMARY AND CONCLUSION

Nutrient management conventionally focused on enhancing the economic returns from nutrients used to produce a crop. At present, nutrient management also has started to include ways to reduce the negative impact of applied chemical nutrients on the environment. Sustaining soil and soil fertility in intensive cropping systems for higher yields and better quality can be achieved through better management of fertilizer application. Thus, information on fertility status of soils and crop response to different soil fertility management is very crucial to come up with profitable and sustainable crop production.

Determining the in-season N status of the crop using a handheld NDVI sensor is one of the effective ways for N management for Ethiopian smallholder farmer. The mean yield components of quality protein maize variety were significantly affected by application of N rates at planting and side dressing. Significant differences were observed on measured NDVI and INSEY at V4 growth stages of maize. There was a strong relationship and significant correlation between NDVI and grain yield up to 100kg N ha^{-1}. Correlation analysis of harvested grain yield shows a higher correlation coefficients (0.78) between grain yield and NDIV and INSY at V4. Similarly, the NDVI reading and calculated INSEY at V6 have correlation with grain yield (0.79 and 0.75). Significantly higher mean grain yield of quality protein maize variety was obtained between 63 kg ha^{-1} N (25 kg ha^{-1} at planting with 38 kg ha^{-1} side dressing) to 100 kg ha^{-1} N (25 kg ha^{-1} at planting with 75 kg ha^{-1} N applied as side dressing).

Overall, the NDVI sensing technique was reasonably successful in predicting the optimum nitrogen fertilizer rates. Quality protein maize growing farmers in Bako, Western Ethiopia will be able to maximize profitability by applying the right amounts of nitrogen. If realized by improving fertilizer nitrogen use efficiency, this might translate into less excess nitrogen to pollute groundwater. The grower can adjust nitrogen fertilizer rates based on the season, with NDVI sensing providing valuable information on when, where, and how much nitrogen to apply.

Application of 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} side dressing had the higher net benefit of ETB 53590 ha^{-1}. In conclusion, application of nitrogen fertilizer at the rate of 63 kg N ha^{-1} (25 kg N ha^{-1} N at planting with side dressed by 38 kg N ha^{-1}) gave higher grain yield and net benefit of quality protein maize variety in the study area. Therefore, application of 25 kg N ha^{-1} at planting with 38 kg N ha^{-1} for side dressing was recommended for quality protein maize varieties in Bako and similar agro-ecologies.

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APPENDICES

Appendix table 1. Mean square of phenological growth, grain yield and yield components of QPM under different levels of nitrogen fertilizer at Bako

S. V	df	PH (m)	LA (cm^2)	LAI	GY (t ha^{-1})	DB (t ha^{-1})	HI (%)	TKW (g)
			MS					
N	2	0.080**	1123746**	0.310**	5.41**	45.57**	1.79**	443.36**
SD	3	0.007	75193**	0.022*	0.89**	8.26**	0.97*	123.43*
N * SD	6	0.004	71068**	0.017*	0.29**	2.34**	1.80**	100.46*
Rep	2	0.032**	10720	0.003	1.65**	55.08**	3.20**	86.03
Error	22	0.004	8252	0.004	0.03	0.86	0.18	28.99

* and ** significant at 5% and 1% probability level, S. V= Source of variation, MS= Mean square, N= nitrogen rates applied at planting, SD= nitrogen rates for side dressing, df= 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= 1000 kernel weight

Appendix table 2. Mean square of normalized difference vegetative index (NDVI) reading and in season estimation of yield (INSEY) of quality protein maize under different levels of nitrogen fertilizer at Bako

Source of variation	df	NDVI at node			INSEY at node		
		initiation	elongation	V8	initiation	elongation	V8
			MS				
N	2	0.0613**	0.0382**	0.0436**	5.551**	3.508**	3.738**
SD	3	0.0006**	0.0002	0.0005	8.744*	1.063	4.006
N * SD	6	0.0022**	0.0003	0.0002	2.475**	1.722	1.903
Rep	2	0.0002	0.0016	0.0069	1.420**	1.722	5.929
Error	22	0.0001	0.0007	0.0007	1.429	8.615	5.664

* and ** =significant difference at 5% and 1% probability level, df= degree freedom and MS= Mean square, N= nitrogen rates applied at planting, SD= nitrogen rates for side dressing

Appendix table 3. Rainfall, temperature and relative humidity data for the Bako Agricultural Research Center, 2016

	Rainfall (mm)												
Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
Mean	3.2	2.9	12.8	58.0	220.3	297.3	184.2	236.1	222.8	79.1	0.0	0.0	1316.7
	Temperature (0c)												Mean
Minimum	14.3	12.7	14.1	14.3	12.8	14.7	14.8	14.6	14.6	14.9	14.6	10.6	13.9
Maximum	31.1	32.4	34.4	34.6	32.4	26.5	25.5	24.8	26.3	28.6	29.8	30.1	29.7
Mean	22.7	22.6	24.3	24.5	22.6	20.6	20.2	19.7	20.5	21.8	22.2	20.4	21.8
RH (%)	46.4	46.2	45.5	46.0	49.0	52.3	56.3	56.6	53.0	51.7	50.0	49.0	50.2