Narrowing Maize Yield Gaps Under Rain-fed conditions in Tanzania: Effect of Small Nitrogen Dose

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Abstract

The wide gap between potential and actual yields of maize in Tanzania, due to low productivity is the major constraint to improvement of food security and livelihood of farmers. The objective of this study was to evaluate the potential of the use of small amount of nitrogen fertilizer as a measure to reduce maize yield gap under rain fed conditions. Field experiments were conducted at Sokoine University of Agriculture, Morogoro during the dry and rainy seasons of 2012/2013 using Maize cultivar PIONEER PHB 3253. The nitrogen application rates were 0 (control), 15 (low N dose) and 80 kg N ha^{-1} (recommended rate). Three water application regimes were tested. Irrigation water was applied from crop establishment up to; grain filling; 50% anthesis; and between 50% anthesis and grain filling. The treatments were applied in a completely randomized block design, in factorial layout for the dry season experiment. Nitrogen treatments were repeated during the 2012/2013 rain season under rain-fed conditions. Both experiments were replicated three times. In a dry season experiment, the water application regimes significantly ($P \leq 0.05$) increase biomass at both 50% and harvest maturity stages. Total tissue N content decreased under non-stressed water regime relative to water-stressed treatments. The interaction between irrigation and nitrogen treatments significantly ($P \leq 0.05$) affected grain yield. Application of recommended N rate did not result into yield increase when water was limiting. In the rainy season experiment, recommended N rate resulted in highest biomass at end of juvenile (1 t ha^{-1}), 50% anthesis (7.7 t ha^{-1}) and harvest maturity stages (13.1 t ha^{-1}). Total tissue N content and grain yield increased significantly with increase in N application rates during the rainy season. Under water stress conditions, low N dose produced an extra 1000 kg ha^{-1} grain yield over absolute control treatment. Under water stress conditions, recommended N rate, a 54% reduction of yield gap was observed, which could not sufficiently reduce yield gap. However, under adequate soil moisture conditions, recommended N rate attained up to 26% yield gap, suggesting that it would be beneficial to apply nitrogen fertilizer when water is not limiting to close the yield gap. Small nitrogen doses can be an effective strategy towards narrowing yield gaps for resource poor farmers especially in drought prone areas. Further study should be done to extend the results beyond experimental site to test and validate the approach under farmers' paradigms.

Keywords: potential yield, water stress, soil fertility, Maize, Tanzania,

Introduction

Low soil nutrients and water availability to crop are among the major constraints to crop productivity in the world (Hengsdijk and Langeveld, 2009). As a result yields of major food crops have been low and stagnated in most developing countries including Tanzania. Observed increase in food production in Tanzania has mainly been due to expansion of agricultural land (FAO, 2014), which is not sustainable due to loss of biodiversity and potential land degradation (Cassman *et al.,* 2002;

van Ittersum *et al.,* 2013). In Tanzania, the number of chronically hungry people rose from 28.8% in 1992 to 33% in 2013 (FAO, 2014), suggesting that food supply has not matched with the demand. Moreover, despite 2.6% annual population growth rate between 1988 and 2002 in Morogoro Region, (United Republic of Tanzania - URT, 2013) maize yields declined from 2.1 tons ha^{-1} in 1994/95 season to 1.0 tons ha^{-1} in 2007/08 season (URT, 2012). Thus sustainable agricultural intensification through soil fertility and water management to increase food productivity per unit area without degrading the environment is inevitable to attain food security (Inter Academy Council, 2004; New Partnership for Africa's Development - NEPAD, 2003; The Montpellier Panel, 2013).

One of major challenges for food security is how to improve productivity under current crop land. Under rain fed conditions, maize, like any other crop faces periods of water stress at certain stages during its growth cycle, reducing possibility of attaining its potential growth and yield. Cognisant of rainfall pattern and associated risk of crop failure due to unreliable precipitation, farmers may be reluctant to invest in inputs and land management (Barron *et al.,* 2003; de Fraiture *et al.,* 2009).

Maize grain yield varies with levels of soil fertility and fertilizer use. One of the most limiting nutrients for crop growth and yield is nitrogen. Yin *et al.* (2014) indicated that nitrogen was the main factor for determining maize grain yield followed by water availability while phosphorus played a relatively minor role in semi-arid conditions of Northeast China. This is because N is naturally low in soils with low soil organic matter and is subject to losses through leaching, immobilization, mobilization and soil erosion (Brady and Weil, 2008). If soil fertility is well managed, rain fed dependent crop production turns out to be productive and substantial productivity improvement can be realized (Kalhapure *et al.,* 2013). However, it is reported that up to 89% of fields under annual crops do not receive any kind of fertilizer in Morogoro region because of high fertilizer costs (URT 2012).

In semi-arid southern Zimbabwe, as low as 8.5 kg N ha^{-1}, in combination with 3 t ha^{-1}, maize yield increased from 1.26 t ha^{-1} (control) to 2.5 t ha^{-1} when there was good seasonal rains (Ncube *et al.,* 2007). Tittonell *et al.* (2008) reported that fertilizer addition (30 kg P ha^{-1} + 90 kg N ha^{-1}) under rain fed conditions could increase maize yield yields and hence bridge the yield gap in Western Kenya. The question is how much yield gain is possible if a small nitrogen dose or recommended nitrogen rate is applied onto a maize crop under low and high seasonal precipitation? It is this set of scenarios which is not well documented not only in the study area, but also in Tanzania. With uncertain seasonal rainfall and high fertilizer costs, some farmers may not apply any fertilizer at all. Consequently, maize yields will be low, even with good seasonal rains. Thus there is a need to investigate the importance of these growth resources as means of reducing maize yield gap. Low N rates could be an option for fertilizer management, for enhancing productivity under uncertain, rain fed conditions. This study will contribute to effective prioritization and allocation of resources needed to enhance maize productivity in small scale farming environments. Moreover, the results from the yield gaps study may be important inputs into economic models that assess food security and land use.

Thus the aim of this work was to demonstrate the use of low dose of nitrogen fertilizer as a measure to reduce maize yield gap under rain fed conditions. Specifically, it aimed at: (i) determining the effects of low dose of nitrogen dose on growth and yield of maize at varying levels soil moisture availability, and, (ii) evaluating the effects of nitrogen fertilization on reducing maize yield gap.

Materials and methods

Description of the study area

Studies were conducted at the Crop Museum, located within the main campus of Sokoine University of Agriculture (SUA) Morogoro, Tanzania (6.85°S, 37.65°E). The area has a sub humid climate with mean annual temperature of 24°C and iso-hyperthermic mean annual soil temperature. The soils are highly weathered and classified as *Utisols* (USDA Taxonomy) or Acrisols (FAO-UNESCO soil classification) with Ustic soil moisture regime (Msanya *et al.,* 2003).

Soil Sampling and analysis

One week before sowing, composite soil samples were collected from the experimental site using regular grid method (Paetz and Wilke, 2005) for physical and chemical characterisation. Samples were collected from depths of 10, 40 and 65 cm and from depths of 10, 30, 50 and 75 cm during the dry and rainy season respectively. Nine spots were randomly chosen for each sampling depth. The samples were composited on a clean plastic sheet, air-dried, and ground to pass through 2 mm sieve for analysis in Soil Science laboratory at SUA. The samples were later analysed for texture, organic carbon (OC), total nitrogen content, soil pH, available phosphorus and exchangeable potassium contents. Soil texture was determined using Bouyoucos hydrometer method; OC was analysed following the Walkley-Black method (Motsara and Roy, 2008); total soil N was analysed using modified Kjeldahl procedure (Wilke, 2005); Soil pH was measured by a glass electrode using soil to water ratio of 1:2. Available P was extracted using the Bray 1 method and determined by spectrophotometric procedure (Wilke, 2005). Exchangeable potassium was extracted using neutral, 1.0 M ammonium acetate and estimated using a flame photometer.

Field experimental design

Two field experiments were conducted, one during the dry season of 2012, and another during rainy season of 2013, The dry season experiment was conducted from July to October and consisted of three levels of nitrogen application; 0, 15 and 80 Kg N ha^{-1} and three irrigation regimes that started at crop establishment and stopped (i) at grain filling (continuous irrigation); (ii) at 50% anthesis (late stress); (iii) between crop establishment and 50% anthesis (early water stress). The treatments were arranged in a completely randomized block design in a factorial layout. Irrigation water was applied via furrows along the crop rows and a flow meter was installed to measure water volume per application. Irrigation regimes were based on daily plant requirement for non-stressed treatments (Figure 1). Crops grown under late, early and no water stress received 309 mm, 202 mm, 434 mm respectively.

The rainy season experiment was conducted from March to July in a completely randomized block with three replicates. Nitrogen application rates were similar to the dry season experiment and there was no irrigation. During the rainy season experiment the total rainfall received was 250 mm for the growing season (Figure 2). The precipitation was uniform during the period of linear crop growth. Up to 97% of seasonal rains was received within 60 days after sowing, the remaining of which was received after wards during grain maturation.

In both experiments phosphorus, as triple super phosphate (TSP) fertilizer was broadcasted uniformly to all experimental plots at the rate of 30 kg P ha^{-1} during sowing. Low dose of nitrogen (15 kg N ha^{-1}) was applied using Urea fertiliser banded about 5 cm around of the plant, 28 days after sowing (DAS). The recommended N rate was applied in splits of 40 kg N ha^{-1} at 10 and 45 DAS. These doses were compared to untreated control. The choice of application rates was based on practice of small holder farmers, who either apply very little or do not apply fertilisers at all.

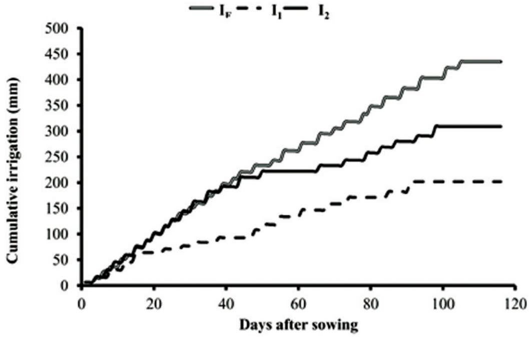

Figure 1: Cumulative water application in three irrigation treatments (IF = water supply as per crop requirement; I1 = water stress between crop establishment and 50% anthesis; I2 = water stress between anthesis and grain filling).

Maize cultivar used in this study was PIONEER PHB 3253 and plant population was 44,000 plants ha^{-1}. PIONEER PHB 3253 is a hybrid maize cultivar with white and hard flint kernels, adapted to low and medium altitude (Lyimo *et al.*, 2014). It is a high yielding, resource intensive crop cultivar a hybrid which needs more water and more fertilizer. The plot size during dry season experiment was 20.8 m^2 (4.0 x 5.2) with six rows and 10 plants per row while in the rainy season experiment, the plot size was 18.9 m^2 (5.25 x 3.6 m) with 5 rows and 10 plants per row.

Data Collection

Plant sampling was done at three growth stages; during end of juvenile stage, 50% anthesis and harvest maturity. End of juvenile stage refers to the pre-induction stage when the plant is not sensitive to photoperiod (Ritchie, 1993). This is the stage shortly before flower initiation when the final leaf number is determined. At each sampling stage, four plants were cut just above the ground for dry biomass measurements. Yield components; grain number/ear, individual grain weight and tops weight were recorded at harvesting. Also, shoots were separated from the kernels, sheaths and cobs and oven dried at 70°C until a constant weight was attained. A subsample from each component was ground separately and analysed for total N concentration (g N/g dry matter) using Kjeldahl wet digestion method (Motsara and Roy, 2008). Nitrogen content values from each component were averaged to determine overall plant N content.

Plant samples were prepared as in the dry season experiment for determination of above-ground biomass, yield and yield components and tissue nitrogen content.

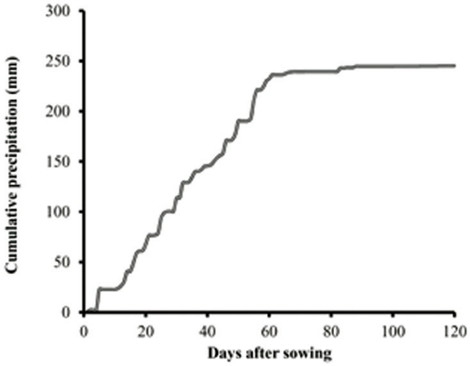

Figure 2: Cumulative precipitation for the March-June 2013 rain-fed experiment at Sokoine University of Agriculture Crop Museum site, Morogoro, Tanzania

Yield gap was calculated as the difference between potential yield and actual yield obtained from nitrogen treatments for both dry and rainy season experiments and irrigation regime treatments for dry season experiment. The yields for PIONEER 3253 PHB reported in previous work by Mourice *et al.* (2014) was considered to be the potential yield because, water and nutrients were adequately supplied and all growth limiting and growth reducing factors were sufficiently controlled.

Statistical analysis

Inferential statistical analyses (analysis of variance) were conducted using GENSTAT v.14 software (VSN International, UK). Least significant difference (LSD) was used to compare means and where applicable, mean ranking was done using the Turkeys test at 5% significance level.

Results

The experimental site had a soil pH of 5.7 which is moderately strong acid, with medium soil organic C of 1.7 to 1.8%, and low total N (0.04 to 0.14 %) (Table 1, Table2). The available P ranged from 7.7 to 8.3 mg kg^{-1} while exchangeable K is high (0.7 cmol (+) kg^{-1}) (Table 1 and 2). All the measured soil fertility parameters decreased with depth. The textural class of surface soil is sandy clay and clay content increased with depth, which is not expected to limit maize growth and yield. Generally the fertility status of the experimental site is low due to acidic pH, low N, and P.

Dry season Experiment

On set of leaf senescence and maturity were recorded earlier in water stressed than in continuously irrigated plants. Consequently, water application stopped earlier in water stressed plants. According to Pic *et al.* (2002), mild water stress accelerates leaf senescence by 15 days in peas (*Pisum sativum* L.), compared to fully-watered plants. Thus, irrigation can continue depending on presence of green leaves and vice versa.

Effects of water regimes and Nitrogen levels on maize plant biomass

No significant effect of water supply on above ground biomass of the plants at the end of juvenile stage, but the effects were significant (P<0.05) at both 50% anthesis and harvest maturity stages. Generally, for all growth stages, the above ground biomass was the lowest in plants subjected to early water stress and highest in continuously irrigated plants. Nitrogen dose significantly affected the above ground biomass for all growth stages. However, there was no significant irrigation x

Table 1: Soil physical and chemical properties of the experimental site during the dry season (July-October 2012) one week prior to planting

	Soil texture								
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Class	OC (%)	Total N (%)	pH (H20)	PBRAY (mg/kg)	Kexch. (cmol (+)/kg)
10	46	8	46	SC	1.7	0.11	5.7	7.7	0.69
30	47	9	44	SC	1.1	0.08	5.3	5.4	0.22
50	60	9	31	C	0.7	0.05	5.5	4.8	0.10
75	68	9	23	C	0.5	0.05	5.4	4.9	0.06

SC = Sand Clay, C = Clay, OC = Organic carbon, N = Nitrogen, P = Phosphorus, Kexch. = Exchangeable Potassium,

Table 2: Soil physical and chemical properties of the experimental site during the rainy season (March –June 2013)

	Soil texture								
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Class	OC (%)	Total N (%)	pH (H20)	PBRAY (mg/kg)	Kexch. (cmol (+)/kg)
10	48	10	42	SC	1.8	0.14	5.7	8.3	0.72
40	63	9	28	C	0.9	0.10	5.4	6.1	0.44
65	63	9	28	C	0.5	0.04	5.2	4.4	0.25

SC = Sand Clay, C = Clay, OC = Organic carbon, N = Nitrogen, P = Phosphorus, Kexch. = Exchangeable Potassium,

nitrogen treatment interaction effects on biomass for all growth stages.

Effects of water regimes and Nitrogen levels on tissue N content

Irrigation regimes significantly (P<0.05) affected total tissue nitrogen content of the plants. The amount of tissue N was higher in early water stressed than continuously irrigated plants. Similarly, the effects of N levels on total tissue N content were significantly (P<0.001) different. The total tissue N content was lower in plants grown under low N dose (3.8%) than in plants under recommended N dose (5.6%). However, there was no significant effect of the interaction between irrigation regime and nitrogen levels.

Effects of water regimes and N levels on grain yield

Interaction between irrigation and applied nitrogen levels had significant effects on maize grain yield (P<0.05) (Figure 3). Low grain yields were recorded where nitrogen was not applied, regardless of irrigation regime. High grain yields were obtained in crops supplied with the highest Nitrogen level (80kg N ha$^{-1)}$, also regardless of the irrigation regimes. Highest grain yield of 4.7 t ha^{-1},was recorded in a crop grown under highest level of nitrogen without moisture stress. It is evident that nitrogen played a profound role in increasing grain yield in every irrigation regime.

Rainy Season Experiment

Effects of Nitrogen levels on maize plant biomass

During the rainy season, nitrogen levels significantly (P<0.05) affected above ground biomass at all growth stages (Table 3). Low above ground biomass during the dry season could be due to low air humidity due to increased wind speed and temperature. Low humidity and higher temperature increase evapotranspiration and respiration hence high water loss. In this case, some assimilates are allocated for respiration process, unlike during the rainy season when air humidity is high and temperatures are cool. The above ground biomass was significantly (P<0.5) higher (1000 to 13088 kg ha^{-1}) in crops grown under recommended N rate than in untreated control (612 to 6320 kg ha^{-1}) (Table 3).

Effects of applied nitrogen levels on tissue N and maize grain yield

The effect of nitrogen fertilization on total tissue nitrogen content was highly significant in the rainy season experiment. Total tissue N ranged from 2.8% to 5.8%, from untreated control to recommended N rate respectively (Table 3). Grain yield, increased significantly with increase in nitrogen levels. Grain yield increased by 65% and 240% in a low dose and recommended N rate respectively, over control (Table 3).

Yield Gap Analysis

From the previous work by Mourice *et al.* (2014) the potential yield for the maize cultivar PIONEEER PHB 3253 (6318 Kg ha^{-1}) was used in this study. Under water-stressed to 50% anthesis treatment, maize yield gap declined from 74% at control nitrogen application to 54% at recommended N rate (Table 4). When the crop was water stressed between 50% anthesis and grain filling, the maize yield gap declined from 73% at control N to 43% at recommended N rate. Furthermore, at non-stressed water regime, the level of yield gap was higher than in water-stressed to 50% anthesis water regime at control N. However, the yield gap declined with increase in nitrogen levels to a minimum of 26% at recommended N rate when there was no moisture stress (Table 4).

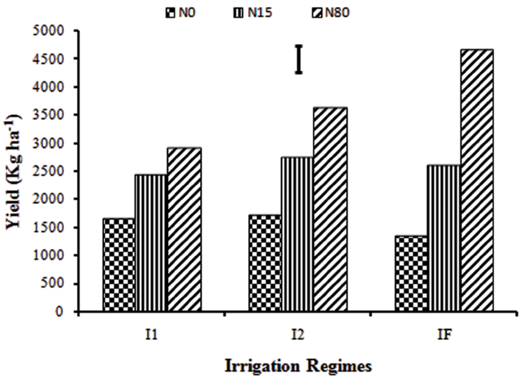

Figure 3. Effects of irrigation regimes and nitrogen levels on grain yield of maize grown during the dry season in Morogoro region, Tanzania. Vertical bar indicated the least significant difference (LSD)

Discussion

Fertility status of the soil determines yield and response of crops to fertilizer and water management. The site used for this study can be characterized as less fertile due to its low nitrogen, low phosphorus and marginal organic carbon content in the top soil. The soil is acidic, a characteristic of highly weathered soils found at the study site and surrounding areas. The fertility status of the study site suggests the need for soil fertility amendments using non-acidifying nitrogenous and phosphorus fertilizers for optimum crop production (Msanya *et al.,* 2003).

Plant nutrients and water improve crop productivity because plant biomass development is a response to water and nutrients availability. When water is limiting, stomatal pores close in order to limit water loss, consequently restricting the entry of carbon dioxide into the leaf which in turn affects photosynthesis. That is why plants under water stress have low biomass than those under sufficient water supply (Eck, 1986). Cakir (2004) reported that vegetative and yield parameters are significantly affected by water shortage during the sensitive tasseling and cob formation. This is in agreement with the effects of stressing maize plants up to 50% anthesis on vegetative biomass and yield in this study.

Nitrogen fertilization has an effect on biomass as early as 14 days after sowing as evidenced by the differences among nitrogen treatments. This suggests that applying sufficient nitrogen at the beginning of crop growth (starter N) provides a good head start to crop development. Early crop establishment leads to better competition against weeds and may result into strong roots system which would enhance water absorption and utilization, unlike in non-fertilized plants (Radma and Dagash, 2013). The canopy size which translates into photosynthesizing surface is different between fertilized and non-fertilized crop plants. Nitrogen deficiency in soil causes small maize leaf size and less carbon fixation as compared to sufficiently fertilized plants (Paponov and Engels, 2003).

The response of plants to N fertilisers is dependent on available soil water. Applying large amounts of fertilizer when moisture is limited may not increase yield. At any given irrigation regime, recommended N rate led to higher grain yield compared to low N rate. However, the yields obtained under

Table 3: Effects of nitrogen levels on above ground biomass, tissue nitrogen content and grain yield of maize grown duringthe rainy season in Morogoro region, Tanzania

	Biomass (Kg ha^{-1})				
Treatment	**Juvenile stage**	**50% anthesis**	**Harvest maturity**	**Total tissue N content (%)**	**Grain yield (Kg ha^{-1})**
N0	612b	3663 c	6320 c	2.8 b	1533 c
N15	622 b	6369 b	10525 b	3.6 b	2527 b
N80	1000 a	7738 a	13088a	5.8 a	5198 a
Significance	*	***	***	***	***
LSD (5%)	231	612	1593	0.8	365
CV (%)	4.7	4.6	7.0	8.7	5.2

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).
*, **, *** = Significant F values at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively; NS: not significant.

Table 4: Maize yield gap under three water regimes and three nitrogen levels.

	N0	**N15**	**N80**
Potential yield (Kg ha^{-1})	6318	6318	6318
Observed yield in I1 (Kg ha^{-1})	1667	2432	2920
Yield gap in I1 (%)	74	61	54
Observed in I2 (Kg ha^{-1})	1732	2754	3627
Yield gap in I2 (%)	73	56	43
Observed yield in IF (Kg ha^{-1})	1355	2605	4664
Yield gap in IF (%)	79	59	26

recommended and low N dose were not significantly different when the crop was water stressed during the initial stages. Results of this study suggest that plant biomass accumulation depends on availability of both water and nutrient. Crop yield would be low when either water or nutrients are limited. This is because water uptake depends on the size of evaporative surface (crop canopy size) which in turn depends on the level of nutrients available in the soil (Pandey *et al.,* 2000).

Grain yields were similar in all water stressed treatments regardless of N dose, suggesting that water stress imposed after critical growth stage has no significant effect on final grain yield. The probable explanation is that within 45-50 days after sowing, the plant should have accumulated the required biomass for grain formation and filling, and water stress occurring afterwards has no any effect on yield. Likewise, in the rain fed experiment, crop plants would give an optimum yield even if the rains decline just after grain filling. It is important to consider the amount of available water, whether from rain or irrigation, even though grain yield increases with nitrogen dose. Where water is limiting, it may be not be justifiable to apply the recommended dose of N, because there would be little gain in yield. On other hand, a low nitrogen dose (e.g. 15 kg N ha^{-1}) would result into better yield gains than absolute control. Under high rainfall environments, high or recommended N dose is very important in order to take the advantage of readily available soil water to enhance farm productivity, as evidenced from the non-stressed irrigation regime and recommended N dose in this study.

There is a big difference in yield obtained with and without nitrogen fertilizer. Applying low doses of nitrogen reduced the maize gap to 59%, suggesting that there is approximately 1000 kg ha^{-1} grain yield increment with only 15 kg N ha^{-1} fertilizer input. Extra 1000 kg ha^{-1} of maize grain from same piece of land would make a difference in terms of improved food security and livelihood at household level even when the cost of fertilizer is deducted.

The application of low N dose may be advantageous in semi-arid areas, for example parts of Dodoma region where seasonal rains range between 250-300 mm (International Union for Conservation of Nature (IUCN) 2010). In such conditions, adding a small nitrogen dose would result into approximately 760 kg ha^{-1} yield gain over non fertilized crop, which would also make a difference to a resource poor farmer in terms of food security and income. Ncube *et al.* (2007) reported substantial yield gains by about 100% when small nitrogen dose of 8.5 kg N ha^{-1} in combination with 3 tons ha^{-1} of cattle manure was applied in semi-arid southern Zimbabwe. However, small scale, resource poor farmers may not afford large quantities of manure. Livestock keeping which would be the source of farmyard manures is done extensively and away from villages and arable lands thus the accessibility of manure becomes difficult. Transport of manure from bomas to maize fields means extra costs, including labour (Kaliba *et al.,* 2000).

Using large quantities of nitrogen fertilizer may not be justified where soil water is limited. This is because plant growth rate and hence high water demand caused by nutrient availability cannot be satisfied by insufficient water as a result of insufficient rains. A reduction of yield gap by 54% can be attained, which may not be economically justified. In environments with low to medium seasonal rains, low nitrogen dose would also be beneficial, sincethere would be approximately 1000 kg ha^{-1} grain yield increase over non fertilized farm fields. Also using more fertilizer under in this type of environment would not be beneficial either, because yield gap reduction would only be 44%. Kaliba *et al.* (2000) pointed out that rainfall availability was among the key factors to adoption of fertilizer use in maize production. In environments with high seasonal rainfall, two scenarios are possible depending on resource endowment of the farmer. For resource poor farmer, applying lowdose of nitrogen would still be beneficial since the yield gain is approximately 1300 kg ha^{-1} over unfertilized crop. On the other hand, more endowed farmers, who can afford high fertilizer rates would still benefit from it because yield gap reduction would be 26%. Lobell *et al.* (2009) pointed out that yield may not exceed 80% of the potential because this yield level may approximate an economic optimum of major cropping systems.

Conclusion

This study explains the importance of nitrogen use as a strategy towards narrowing maize yield gaps, especially in areas characterised with low and/or unreliable rainfall and low soil nitrogen for crop production. For resource poor farmers, low dose ofnitrogen fertilizer applied after crop establishment may make a substantial contribution to the food security over non-fertilized crop production. This approach can work well in environments with low seasonal rains because yield gain is higher than when high nitrogen quantities are applied in water scarce environment. Under moderate to high rainfall environment, low dose of nitrogen would still be beneficial for resource poor farmers, although higher nitrogen rates may give higher grain yields, if farmers can afford fertilizer costs.

The limitation of this study is that the yield gap narrowing strategy was evaluated at a plot scale. Considering heterogeneity in soil nutrients, soil organic matter content, available water capacity and weather variations in space and time, further study is needed to investigate the necessary response of small nitrogen doses as a strategy in bridging the maize yield gaps in multiple fields and many seasons especially under farmer's management. A crop modeling approach may work well for as long as model calibration and key model inputs data are ascertained.

Aknowlegement

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