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On-farm irrigated maize production in the Somali Gu season

Ryan Gavin[1], Hussein Haji[2], Nicolas Jelinski[3], Allison Harvey[3] and Paul Porter[1*]

[1]Department of Agronomy and Plant Genetics, 411 Borlaug Hall, University of Minnesota, 1991 Upper Buford Circle, St. Paul, 55108, MN, USA.
[2]Somali Agriculture Technical Group, Safari Complex, Km 5 Road, Hodan District, Mogadishu, Somalia.
[3]Department of Soil, Water and Climate, 439 Borlaug Hall, University of Minnesota, 1991 Upper Buford Circle, St. Paul, 55108, MN, USA.

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Domestic production satisfies less than half of Somalia's cereal requirements. In this study, the Somali Agriculture Technical Group (SATG) evaluated different methods of nitrogen application (Broadcast, Hill, or Row) within an improved irrigated maize production system in Somalia's Lower Shebelle riverine region. This improved system consisted of the best management practices (BMPs) recommended by SATG [mineral nitrogen and phosphorus fertilizers, the pesticide Bulldock® (Beta-Cyfluthrin), and an elevated planting population]. The SATG system was also compared with a zero system, which received the same BMPs less mineral nitrogen, and a traditional farming system, which utilized local, unspecified management practices. The research was conducted on eighty-one farms located near the villages of Afgoi and Awdhegle. In the 2014 Gu season, nitrogen application method did not influence grain yields, stover yields or plant heights, but the SATG system (the Broadcast, Hill and Row treatments) was found to have greater grain yields, stover yields and plant heights than both the zero treatment and the traditional system. Significant location by treatment interactions ($p \leq 0.05$) were observed for grain yield. On farms near Afgoi, the grain yield of the improved SATG system (3,530 kg ha^{-1}) was 48% greater than that of the zero treatment and 64% greater than that of the traditional system. Near Awdhegle, these values were 56 and 73%, respectively (SATG = 5,330 kg ha^{-1}). These interactions can likely be attributed to locational differences in farm management and soil properties. Regression analyses demonstrated that when mineral nitrogen was applied, the greatest yields were found at the highest planting populations and earliest planting dates. These data demonstrate that, by utilizing the simple BMPs prescribed by SATG, Somali farmers can dramatically increase maize yields in the Lower Shebelle.

Key words: Maize, nitrogen, on-farm, plant population, planting date, Somalia.

INTRODUCTION

Somalia is one of the poorest countries on the planet. The east African nation has been plagued by civil unrest and harsh environmental conditions, which have led to a perennial state of food insecurity. In January 2017, nearly a quarter of the Somali population could not meet their daily nutritional needs (WFP, 2017). Domestic agricultural production can be a key component of food security. In Somalia, only about half of the population's cereal

Figure 1. A satellite image of the agricultural region illustrating the location of the Afgoi and Awdhegle villages along the Lower Shebelle River in southern Somalia.

requirements are satisfied by domestic production (FAO, 2012). One of the principle cereal crops in the country is maize (*Zea mays*), but Somali maize production has been highly volatile, with total production levels in 2014 nearly identical to those observed in 1980 (FAO, 2017). In order to combat food insecurity and reduce the country's reliance on imported foodstuffs, domestic agricultural production must increase dramatically.

To address this, the Somali Agriculture Technical Group (SATG, www.SATG.org) has been working to develop agricultural best management practices (BMPs) and extension programs in the country. In 2014, SATG utilized an on-farm participatory research approach to compare their recommended BMPs with the traditional farming practices employing the Lower Shebelle region (Figure 1). This region was chosen as the area of interest for the study because it is the heart of irrigated maize production in the country (FAO, 2013).

The BMPs consisted of an increased planting population, mineral fertilizer inputs, and a pesticide application and were selected by SATG because they have repeatedly proven to be important production factors in other areas of the world. For example, in much of the world, the effect of plant population on grain yield has been well established, with yields tending to exhibit a parabolic relationship with plant population (Tetio-Kagho and Gardner, 1988); however, to date, this relationship has not been examined in the Somali context, and as a result, traditional planting populations among Lower Shebelle farmers vary widely. Similarly, though increasing mineral fertilizer use in sub-Saharan Africa has been identified as an essential strategy for increasing food production in the region (Mwangi, 1996), with the effects of nitrogen fertility amendment on maize grain yield being especially well established throughout the world (Binder et al., 2000), the use of mineral fertilizers is still not common practice in the irrigated maize production systems of the Lower Shebelle (FAO, 2018). Separately and in combination, these production techniques have demonstrated important maize yield effects (Asim et al., 2013), but have not been examined in the Somali context.

As such, there were two objectives of the 2014 Gu season research trial: to compare a maize production system incorporating SATG BMPs to the traditional production system currently employed by Lower Shebelle maize farmers; and to examine whether different methods of nitrogen fertilizer application influenced maize yield and growth parameters within the SATG system. An investigation into the most effective method of nitrogen application was necessary because, while the methods of nitrogen application are many and have become increasingly sophisticated in well-developed agricultural contexts (Ma et al., 2004), farmers in developing countries have fewer options for nitrogen delivery and the economic burden of nitrogen fertilizer requires that it be applied judiciously.

MATERIALS AND METHODS

During the 2014 Gu season, a participatory on-farm research trial

*Corresponding author. E-mail: pporter@umn.edu.

was conducted by SATG in the Lower Shebelle region of Somalia (for details on a similar trial performed in the 2014/15 Deyr season, see Gavin et al., 2018). The Lower Shebelle is the country's principal maize producing region and is characterized by alluvial soils and rainfall-driven seasonality. The area receives approximately 500 mm of rainfall annually and experiences temperatures ranging from 26 to 28°C. The Gu season, which extends from April to June, is the wettest season of the year and serves as the primary maize growing season in Somalia. Normally, farmers can expect anywhere from 200 to 300 mm of rainfall during the Gu season (Muchiri, 2007); however, it should be noted that the 2014 Gu season was especially dry, and at an SATG monitoring station near Afgoi, only 105 mm of rainfall was recorded throughout the entire season (Haji, 2017). Though the maize production systems in the Lower Shebelle are irrigated, seasonal rain failures in the Shebelle river basin can have a major effect on the water level of the Shebelle river and influence a farmer's ability to irrigate.

Soils in the Lower Shebelle region are generally classified as Haplic Vertisols (70%), Fluvisols (11%) or Calcisols (2%) (Jones et al., 2013) in the UN-FAO WRB system (Usterts, Fluvents and, Calcids in U.S. Soil Taxonomy), formed in alluvial sediments deposited over calcareous, unconsolidated and consolidated sedimentary formations (Jones et al., 2013; Gadain et al., 2016). The dominant Haplic Vertisols soil type is characterized by 2:1 clays, smectitic mineralogy, a high cation exchange capacity, and shrink-swell properties.

This trial was unique because of its size and participatory design, which maximizes community involvement and can lead to more effective research and extension results (Macaulay et al., 1999). In the 2014 Gu season, eighty-one farmers participated in the research trial, and each was associated with one of two SATG experiment stations located near the Lower Shebelle villages of Afgoi or Awdhegle (Figure 1). These farmers, forty-one near Afgoi and forty near Awdhegle, worked with SATG-trained advisors to oversee the management, harvest, and data collection of the research plots on their land.

This trial was driven by both research and extension goals and was designed as a multi-location randomized complete block (RCB) experiment in which each participating farmer represented a block nested within either the Afgoi or Awdhegle locations. Each farmer planted five treatments on their land: three SATG treatments, one zero treatment, and one traditional treatment. To achieve this, each participating farmer donated one jibaal (625 m^2) of their land to SATG. This jibaal was subdivided into four 10 m^2 plots, with each subdivision housing one of three SATG treatments or the zero treatment. The traditional treatment was evaluated on farmland adjacent to each SATG jibaal and was managed using each farmers' cultural practices.

The three SATG treatments and the zero treatment were managed using BMPs designed by SATG. These BMPs included mineral fertility inputs, an insecticide application and a relatively high planting population. Supplemental fertility was supplied using two applications of urea, once at planting and once at the V4 growth stage, at a rate of 100 kg ha^{-1} (46 kg N ha^{-1}) each, and a one-time pre-plant application of diammonium phosphate (DAP) at a rate of 200 kg ha^{-1} (36 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1}). The insecticide Bulldock® (Beta-Cyfluthrin) was applied at a rate 5.0 kg ha^{-1} in order to control spotted stem borer (*Chilo partellus*), and a planting population of 53,300 plants ha^{-1}, with a between row plant spacing of 0.75 m and a within row plant spacing of 0.25 m was desired. The zero treatment followed the SATG BMPs but received no urea applications. The traditional treatment received no mineral fertilizers or insecticides and had no specified planting population. All five treatments were planted with the same locally-available, open-pollinated maize variety, "Somtux".

The method of urea application was a factor of interest in this trial, and was represented in three SATG treatments. For these treatments, urea was applied using one of three different techniques: a broadcast application, a hill application and a row application. The broadcast application was performed by evenly applying urea over the entire planting area and then incorporating the urea via a hand hoe; the hill application was performed by applying urea to a small hole that had been dug next to each individual maize plant; and the row application was performed by applying the urea to a trench that had been hand dug along the entire length of each maize row.

For data collection, two 3.0 m^2 subsamples were taken from each plot, and their data were averaged together to provide the treatment data for each farm. The main parameters of interest in this study were grain yield, stover yield, plant height and harvested plant population. Grain and stover yield data were obtained by harvesting the respective plant portions and air drying the material. Grain moisture was obtained using a handheld moisture meter and grain yield data were standardized to 15.5% moisture. Stover moisture contents could not be obtained, which prevented the standardization of stover yields to a specific moisture content. This likely contributed to the abnormally high stover yields observed in this trial. Plant height and harvested plant population measurements were determined at harvest. The precision of grain yield, stover yield and plant height measurements was limited by available technology. Plant height measurements were recorded to the nearest tenth of a centimeter, grain yield to the nearest tenth of a kilogram and stover yield to the nearest half kilogram. The lack of precision in grain and stover yield measurements likely contributed to the relatively high standard deviations observed.

Data analysis was performed using both SAS (SAS, 2016) and R (R Core Team, 2016) statistical software. The SAS software package PROC ANOVA was used to perform an Analysis of Variance (ANOVA) for determining the significance ($p \leq 0.05$) of our independent variables, and Tukey's HSD test was used for mean separation (Table 1). For the ANOVA, the data from one farmer at the Awdhegle location was randomly selected and removed in order to provide a balanced data set across both of the experimental locations. The regression analyses were performed using the entire data set in R.

Although, data on soil properties throughout Somalia and the Lower Shebelle region are limited, topsoil data was compiled [including both novel and legacy (Leenaars et al., 2014) data] from within the study area near Afgoi and Awdhegle, both on selected farms participating in this trial and within a 10 km radius of the experiment stations. This compiled dataset contained pH (1:1 soil/water), electrical conductivity (EC), cation exchange capacity and texture (sand and clay proportions) for eight locations (four at Awdhegle and four at Afgoi).

RESULTS AND DISCUSSION

Analyses of variance

Five different maize management systems were evaluated on eighty-one farms, which were associated with either the village of Afgoi or Awdhegle in the Lower Shebelle, during the 2014 Gu season. Significant treatment by location interactions were observed for grain yield, stover yield and harvested plant population (Table 1). Though these interactions were significant, the interpretation of the data from each of these locations was consistent. The treatment by location interactions that were observed for grain yield and stover yield were the result of differing effect magnitudes between treatments at each location, rather than trend inconsistencies. These differing treatment effect magnitudes were likely

Table 1. The effect of treatment and location on maize production during the 2014 Gu season on farms located near Afgoi and Awdhegle in the Lower Shebelle area of Somalia.

Treatment	Location	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvested plant pop. (ha^{-1})	Plant height (cm)
Broadcast	Afgoi	3500	12100	46920	162
Hill	Afgoi	3640	11600	45800	163
Row	Afgoi	3460	12200	45700	164
Zero	Afgoi	2380	10900	46500	156
Traditional	Afgoi	2150	8930	37700	145
Broadcast	Awdhegle	5390	12600	51800	182
Hill	Awdhegle	5430	13000	52200	187
Row	Awdhegle	5150	12800	51400	182
Zero	Awdhegle	3410	10100	50600	176
Traditional	Awdhegle	3080	7880	32500	169
Treatment averaged across location					
Broadcast	—	4450^{a}	12400^{a}	49330^{a}	172^{a}
Hill	—	4540^{a}	12300^{a}	48980^{a}	175^{a}
Row	—	4300^{a}	12500^{a}	48520^{a}	173^{a}
Zero	—	2900^{b}	10500^{b}	48520^{a}	166^{b}
Traditional	—	2610^{b}	8400 c	35100^{b}	157 c
Location averaged across treatment					
—	Afgoi	3030^{B}	11100	44490^{B}	158^{B}
—	Awdhegle	4490^{A}	11300	47690^{A}	179^{A}
Summary statistics					
Tukey's HSD (Treatment)		370	1230	2340	5.1
Tukey's HSD (Location)		168	NS	1060	2.3
R^2		0.77	0.72	0.71	0.76
CV (%)		22.7	25.2	11.7	6.7
Treatment (P>f)		<.0001	<.0001	<.0001	<.0001
Location (P>f)		<.0001	0.8481	0.0012	<.0001
Treatment × Location (P>f)		0.0002	0.0298	<.0001	0.2506

the result of locational soil characteristic differences, which will be discussed in greater detail below, and significant locational differences in harvested plant population.

Grain Yield

No significant differences between the broadcast, hill and row treatments (henceforth referred to collectively as the SATG treatments) were observed at either location for any parameter of interest (Table 1). In Afgoi, the average grain yield of the three SATG treatments (3,530 kg ha^{-1}) was 48 and 64% greater as compared to that of the zero and traditional treatments, respectively. In Awdhegle, where the average of the SATG treatments was 5,330 kg ha^{-1}, these differences were 56 and 73%, respectively. Across all treatments, grain yield in Awdhegle (4,490 kg ha^{-1}) was 49% higher than that observed in Afgoi. Interestingly, this aligns well with anecdotal evidence suggesting that farmers near Awdhegle are more skilled than those near Afgoi. Though, these data seem to support that belief, underlying chemical and physical soil properties could be major drivers of the locational grain yield differences.

Soils data from the Lower Shebelle region are scarce, but those available demonstrate some potentially important similarities and differences between soils near Afgoi and those near Awdhegle. When examined, pH (mean = 8 ± 0.2), cation exchange capacity (mean = 38 ± 4 cmol kg^{-1}) and clay (50 ± 14%) did not differ significantly between locations (data not shown) and had values consistent with arid region Vertisols dominated by smectitic phyllosilicates (high pH, high CEC and high clay). However, EC and sand proportions did appear to differ significantly between locations. Electrical conductivity values near Afgoi were an order of magnitude higher than EC values near Awdhegle (9.1 ± 6.8 dS m^{-1} and 0.5 ± 0.2 dS m^{-1}, respectively, $p \leq 0.05$, unpaired t-test), and sand percentages were approximately 2-3 times higher near Afgoi (17 ± 6%) as compared to Awdhegle (5 ± 4%) ($p \leq 0.05$, unpaired t-test). Given the very high proportions of clay in these soils (soil textures of silty clay and clay), it is unlikely that differences in sand proportions on the order described here would be large enough to explain the observed differences in yield. However, soil EC can certainly influence crop development (Farooq et al., 2015; Shalhevet et al., 1995), and the strong locational differences in EC may explain at least some of the observed differences in crop growth and yield between the two locations.

Stover yield

Stover yields in the 2014 Gu season must be viewed with skepticism because the stover was air-dried and weight measurements were not standardized to a specific moisture content. That said, major stover yield themes appeared to closely mimic those of grain yield and can be informative. There were no meaningful differences amongst the three SATG treatments in either location, but in both locations, these treatments produced more stover than the zero and traditional treatments (Table 1). In Afgoi, the average stover yield for the three SATG treatments (12,000 kg ha^{-1}) was 10% greater than that of the zero treatment and 34% greater than that of the traditional treatment. In Awdhegle, these differences were 26 and 63%, respectively, with the average stover yield of the three SATG treatments being 12800 kg ha^{-1}. No meaningful difference in overall stover yield between the two locations was observed. This was interesting given the greater harvested plant population observed at Awdhegle, and suggests more moisture laden or poorly dried plants in Afgoi. These treatment differences are unsurprising, and likely result from the increased fertility and plant populations recommended by SATG.

Harvested plant population

Plant populations at harvest did not differ significantly between the three SATG treatments and the zero treatment at either location, though the average harvested plant population of these treatments at Awdhegle (51,500 plants ha^{-1}) was 11% greater than at Afgoi (Table 1). This significant interaction can only be explained by improper thinning. In both locations, the harvested plant population of the three SATG treatments and the zero treatment were higher than those of the traditional treatment. In Afgoi, the average harvested plant population of the SATG and zero treatments(46,200 plants ha^{-1}) was 23% greater than the traditional treatment. In Awdhegle (51,500 plants ha^{-1}), it was 58% greater. Interestingly, unlike the three SATG and zero treatments, the harvested plant population of the traditional treatment in Awdhegle (32,500 plants ha^{-1}) was 14% less than it was in Afgoi. Even though fewer plants were harvested, however, the grain yield of the traditional treatment in Awdhegle (3,080 kg ha^{-1}) was 43% greater than in Afgoi. This further strengthens the above-mentioned argument that the underlying soil characteristics near Awdhegle are more favorable than those near Afgoi and are the primary drivers of locational grain yield differences.

Plant height

No interaction between treatment and location was observed for plant heights, though significant locational and treatment differences were observed (Table 1). Plant heights at Awdhegle, which averaged 179 cm tall across all treatments, were 13% taller than they were at Afgoi. The three SATG treatments were not significantly different from each other, but on average (173 cm), these treatments were 4% taller than plants in the zero treatment and 10% taller than plants in the traditional treatment.

Regression analysis

With eighty-one different observations of each treatment, the size of this experiment also allowed for simple regression analyses to be performed on the relationships that existed between grain yield, plant height, harvested plant population and planting date. When examining these data, it is important to recognize that this study was not explicitly designed to assess these relationships, but because of the dearth of agricultural research in Somalia, it is important to glean knowledge wherever possible.

Planting date

Planting dates in the 2014 Gu season ranged from the 7th of April (day 97 of the year) to the 16th of May (day 136 of the year). A negative relationship between grain yield and planting date was observed for the average of the three SATG treatments, but no relationship was observed between grain yield and planting date for the zero and traditional treatments (Figure 2). This suggests that planting date is not a primary determinate of grain yield in the irrigated maize production systems of the Lower Shebelle during the 2014 Gu season. A more important determinate of grain yield appeared to be adequate fertility, specifically nitrogen and phosphorus

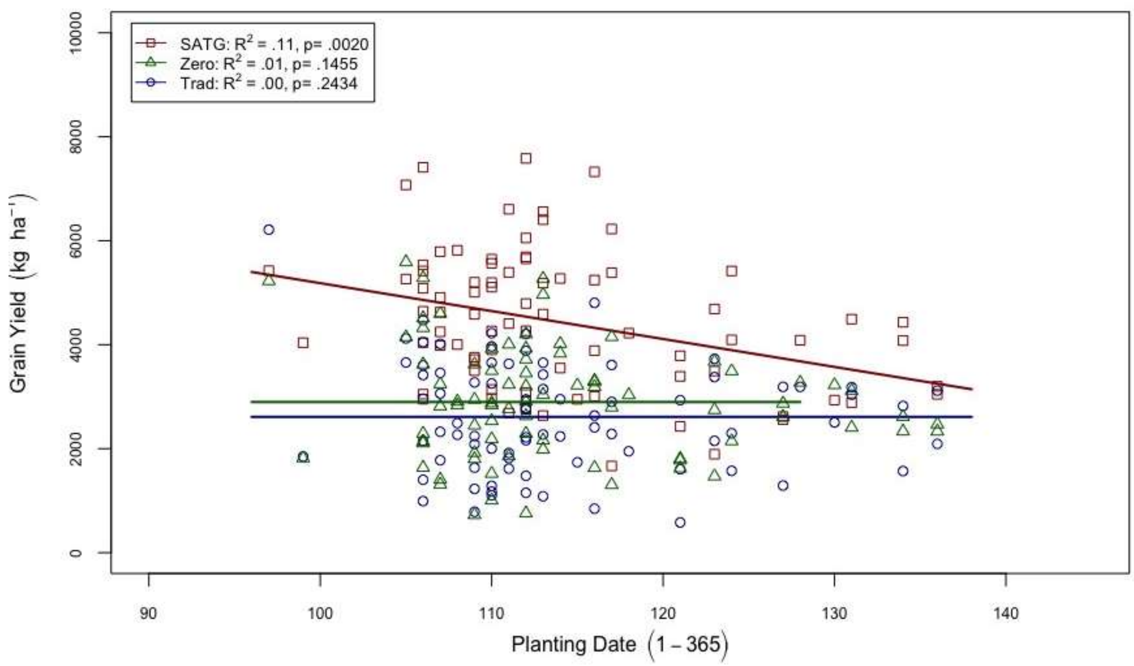

Figure 2. The relationship between planting date (1 = January 1st, 2014) and grain yield under different maize production systems in the 2014 Gu season.

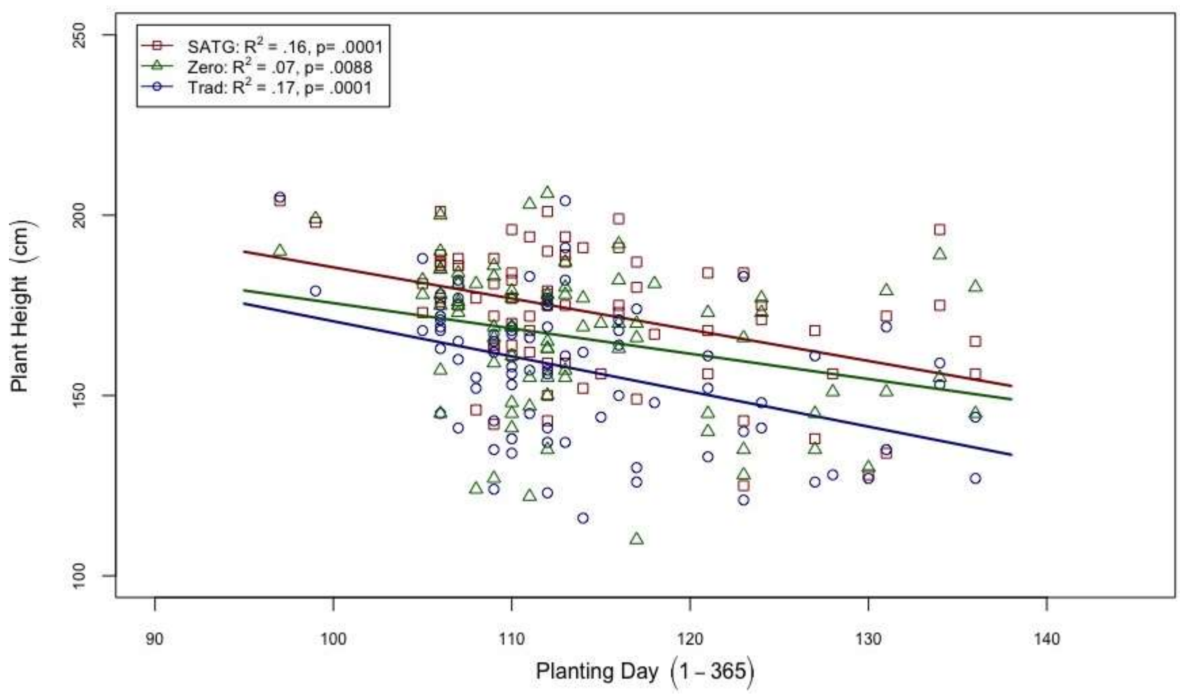

Figure 3. The relationship between planting date (1 = January 1st, 2014) and plant height under different maize production systems in the 2014 Gu season.

availability, but once this fertility was supplied, early planting was advantageous. Planting date also had an effect on plant height (Figure 3). For each production system, later planting dates were associated with shorter

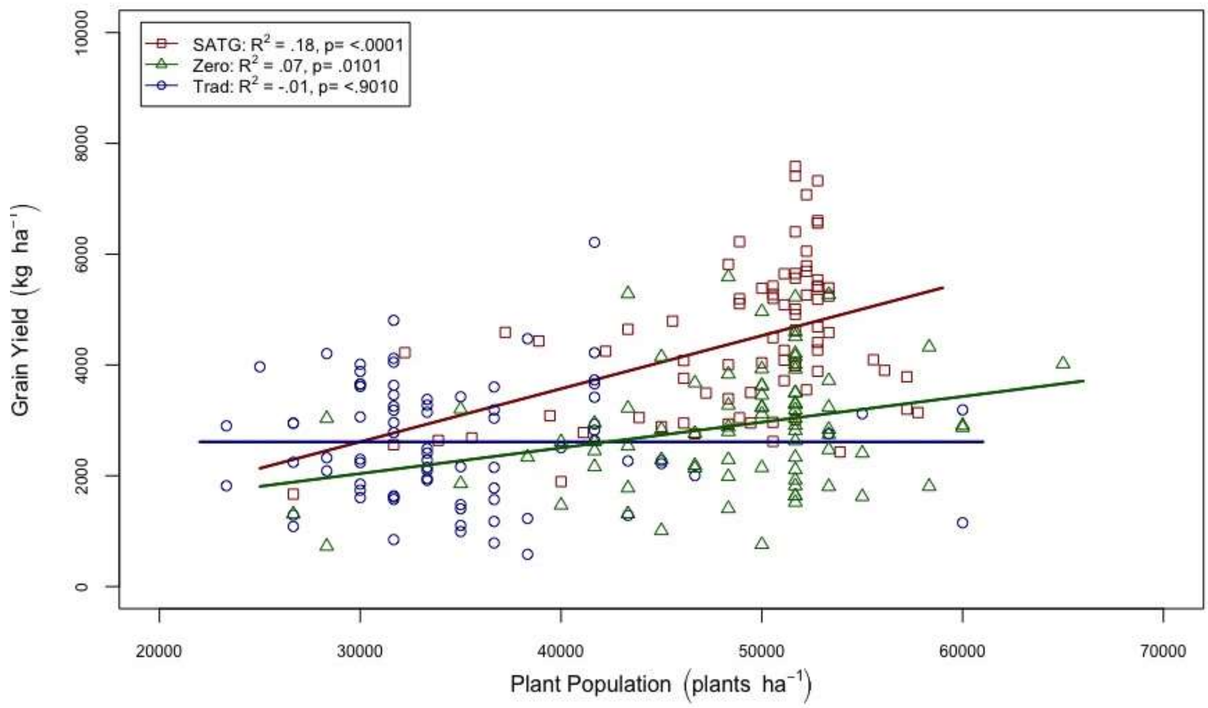

Figure 4. The relationship between harvested plant population and grain yield under different maize production systems in the 2014 Gu season.

plants.

Harvested plant population

A significant positive relationship between harvested plant population and grain yield was observed for both the average of the three SATG treatments and the zero treatment, but no significant relationship was found for the traditional treatment (Figure 4). This is interesting because it suggests that simply increasing the planting population in traditionally managed maize systems will not have an appreciable effect on grain yield in the Lower Shebelle. It also suggests that the low planting populations currently employed by farmers in the region are appropriate for their fertility limitations, and not the result of poor management strategies. When adequate fertility was supplied, however, the positive relationships exhibited by the three SATG and zero treatments suggest that increasing planting populations resulted in higher grain yields. Though the regressions of both the average of the three SATG treatments and the zero treatment were found to be significant and positive, the slope of the average of the three SATG treatments (0.096) was 108% greater than that of the zero treatment. This suggests that the addition of DAP allowed the system to capture some of the yield benefits that come with an increased plant population, but that these benefits require greater nitrogen fertility to be fully realized.

The relationship between harvested plant population and plant height mirrored that of grain yield and harvested plant population (Figure 5). No relationship was observed for the traditional treatment, where plant growth was likely limited by fertility, but positive relationships were observed for the average of the three SATG treatments and the zero treatment, with the average of the three SATG treatments exhibiting the greatest response to increased plant population. This is in line with previous research, which demonstrated a relationship between planting population and plant height (Tetio-Kagho and Gardner, 1988). When plant height and grain yield data were analyzed, a significant positive relationship was observed for the average of the three SATG treatments, the zero treatment, and the traditional treatment, indicating that taller plants yield more grain regardless of treatment (Figure 6).

Conclusion

In this on-farm study, the implementation of SATG BMPs resulted in an irrigated maize grain yield (4,428 kg ha^{-1}) that was 70% greater than that of the traditional farming system employed in the Lower Shebelle region, with larger grain yields being observed at higher harvested plant populations and at earlier planting dates. This work

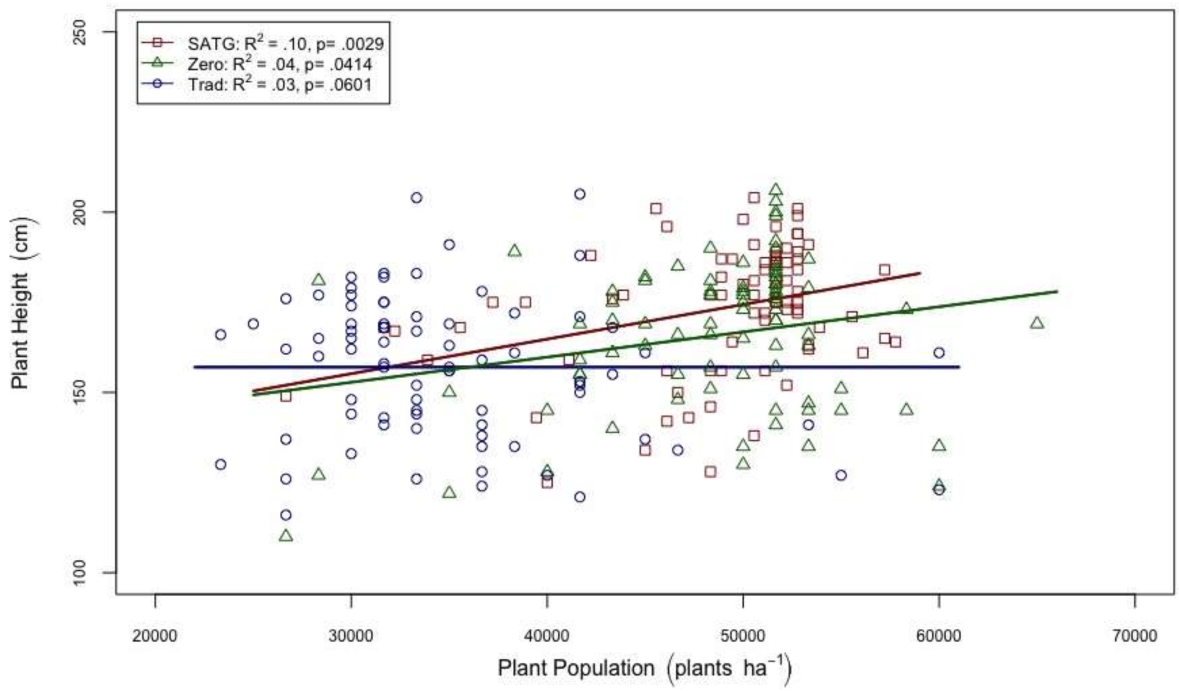

Figure 5. The relationship between harvested plant population and plant height under different maize production systems in the 2014 Gu season.

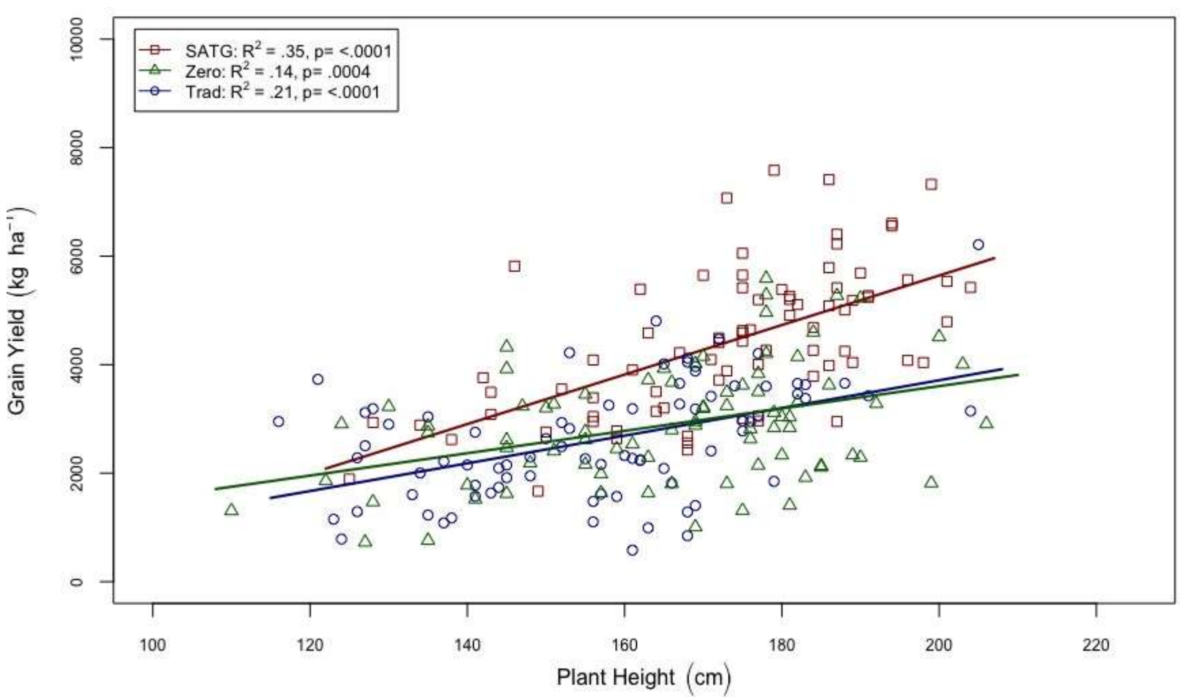

Figure 6. The relationship between plant height and grain yield under different maize production systems in the 2014 Gu season.

method of nitrogen application (broadcast, hill, or row) did not influence grain yield. Though limited in scope, this work constituted one of the first controlled agronomic research trials undertaken in Somalia in more than two decades and was unique in that the research was performed by Somalis, under the supervision of Somalis, and on the farms of Somalis. Future research should focus on better understanding the underlying soil characteristics of the region, performing a true plant population study and testing other maize varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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