Improving the Agronomics and Economics of Cereal Production in Somalia's Lower Shebelle Riverine Region

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Abstract

Somalia has been plagued by conflict since the fall of the Siad Barre government in 1991. This unrest has left the east-African nation with a stagnant economy and multiple stakeholders searching for development solutions. Agriculture remains the country's largest economic driver, and yet less than half of the country's cereal requirements are satisfied by domestic production. The first chapter of this thesis examines historical trends in cereal production, imports, and aid and relates them to population growth and changes in harvested area. It also attempts to understand how the proportion to which each of these fractions contributes to total cereal availability has changed over time and how this has influenced Somali food security and the prevalence of famine.

The second chapter of this thesis focuses on how Somali maize production might be improved. To achieve this, an on-farm field trial, consisting of eighty-one farmers near the cities of Afgoi and Awdhegle, was performed to compare the traditional maize cropping system of the Lower Shebelle riverine with an improved cropping system that utilized a greater planting population and external fertility inputs. This trial took place during the 2014 Gu season. Significant locational differences were observed in the trial, but the overarching story remained consistent across both locations. It was discovered that, while the method of nitrogen application was not a major yield determinate, the improved system resulted in a grain yield that was 70% greater than that observed in the traditional system.

The third chapter of this thesis builds on the 2014 Gu season field trials and examines the effectiveness of an improved cropping system in the 2014/15 Deyr season. To do so, another on-farm field trial consisting of seventy-seven farmers was performed. In this trial, the improved system was even more effective, increasing grain yields by 124% over the traditional system. When a simple economic analysis was performed on these data, it was demonstrated that the improved system required more capital investment but resulted in a net revenue increase of 142%.

Recognizing that increasing farm income is also essential for improving Somali food security, chapter four of this thesis focused on the agronomics and varietal characteristics of the income-generating crop sesame. During the 2016 Hagai and 2016/17 Deyr seasons, five different trials were performed. In each of these trials, variety was determined to have a significant influence sesame seed yield, with the Local variety always among the top performers in terms of seed and stover yield. The addition of urea fertilizer did not significantly affect sesame seed yields, and the differences in planting population observed in this trial were not sufficient to develop a planting population curve or specific recommendations. Planting date, however, did significantly influence sesame plant development, with later planting resulting in shorter, less branched sesame plants.

Together, these trials represent some of the first agronomic research trials to take place in Somalia in over a quarter century and were unique in that they were designed and managed by Somalis, signaling a new-era in Somali agricultural research.

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Chapter 1

Famine and Food: The Contributions of Cereal Production, Imports, and Aid on Somali Food Security in the Last Half Century

Summary

Somalia is among the poorest countries on the planet. Since the fall of the Siad Barre regime in 1991, the country has suffered two officially declared famines and been perennially food insecure. In order to address this issue, a greater understanding of the components that contribute to the Somali food supply is merited. To achieve this, historic trends in the Somali population, cereal production, cereal imports, and cereal aid were analyzed using publically available data from the Food and Agricultural Organization of the United Nations, the World bank, and the World Food Programme. Cereals were the primary focus of this investigation, because they make up anywhere from a third to half of the Somali diet, and low cereal production figures are often cited as the drivers of Somali famine. In mining this data, it was found that Somali cereal production (maize, sorghum, rice, and wheat) hasn't improved since the 1960's and has been characterized by an extreme amount of year-to-year volatility. In that time, the Somali population has more than quadrupled, reducing per capita cereal production from 91 kg in 1961 to just 18 kg in 2014. Today, domestic cereal production only satisfies around half of population needs, and in no year since the fall of the Siad Barre regime has domestic food production been sufficient to stave off famine. As a result, cereal imports and aid have played an increasingly important role in Somali food security, making the country susceptible to disruptions in international markets and foreign government policies. These disruptions played an especially important role in precipitating the 2011 famine. Without significant and widespread economic improvement in the country, which would allow for stable food importation, improving domestic cereal production will be an essential strategy for increasing Somali food security.

Introduction

The Somali Republic, or Somalia, was officially formed in 1960 when the former Italian colony of Somaliland was united with the former British colony of the same name. In that time, the future of a free and independent Somalia was promising, and its early leaders have been remembered as some of Africa's first true democrats (Samatar & Samatar, 2002). During these early years, it's believed that Somalia was nearly completely self-sufficient in terms of food production (Haji, 2017), and historic data suggests that total annual domestic cereal production was near 90 kg per person at that time (FAOSTAT, 2017).

This young democracy, however, did not last long. In 1969, Siad Barre assumed control of the government in a near-bloodless coup and instituted a policy of scientific socialism. This began a period of military rule that would last until the mid-1970's. During this time, the government implemented massive social reforms intended to increase the Somali literacy rate and elevate the rural poor. In the early 1970's, Barre's commitment to rural communities was tested by an historic drought, and resources were rapidly mobilized to avert the impending crisis and famine. Civilian rule was restored in 1976, and though war with Ethiopia was brought to Somalia's borderlands (Lewis, 2003), further rural reforms in the late 1970's set the stage for a golden age of Somali agricultural productivity in the 1980's (Adam & Ford, 1986).

This golden age, however, did not extend to Somali politics. By 1990, foreign support for the Barre regime had diminished, and in 1991, the government in Mogadishu collapsed, leaving the country mired in conflict and political instability (Lewis, 2003). As a result, the productivity of the Somali agricultural sector plummeted and has yet to recover to the per capita production levels observed in the late 1980's (FAOSTAT, 2017).

In famine prone Somalia, domestic crop failures are often cited as the primary drivers of hunger, and while this paper does not refute the assertion that Somali crop production suffered enormously during the 1992 and 2011 famine years, it does seek to better understand the complicated relationships that exist between domestic cereal production, cereal imports, cereal aid, and famine. In this paper, publically available historical data were used to examine the total production, harvested area, and yields of the principle Somali cereal crops. These data were then related to other key contributors of overall food availability in Somalia like cereal imports, cereal aid, and population growth in order to demonstrate that domestic cereal failures alone were not the cause of Somali famine.

Methods

This study's content is entirely based on publically available data and was assembled for analysis using the data generation services of major international agricultural and development organizations. Data related to domestic agricultural production and trade were compiled using the United Nations Food and Agriculture Organization's statistical database (FAO, 2017); human population data were gathered via the World Bank Group's open data portal (WBG, 2016); and the World Food Programme's Food Aid Information System was used to collect data regarding food aid deliveries (WFP, 2017). Given the difficult reporting conditions in Somalia, some of these publically available data should be viewed with skepticism, and suspect data have been noted as such in this report. Further, because the data on these websites is subject to change, it is important to note that the numbers presented here were obtained in August of 2017. All figures were created using the ggplot2 package in the open-source statistical software R (R Core Team, 2016).

Results and Discussion

Human Population in Somalia since the 1960s

The population of Somalia has increased from 2,814,096 in 1960 to 13,513,125 in 2014 (Figure 1). These numbers are based on data compiled from multiple sources by The World Bank Group and should be viewed with some skepticism, because until the completion of the United Nations Population Estimation Survey Somalia in 2014, the most recent publically available government population data came from a 1975 census (UNPF, 2014), in which only limited results were published. Based on The World Bank Group figures, population growth in Somalia between 1960 and 2014 averaged around 3% annually, with the most rapid growth occurring in the late 1970's and relatively flat growth in the 1980's and early 1990's (WBG, 2016).

Somali population growth (Figure 1) closely mirrors its political and social history. Of particular significance are the periods of rapid population growth and decline. Between 1974 and 1979, the Somali population grew at an average rate of nearly 10% annually (WBG, 2016). This growth took place during a period of massive foreign investment by the Soviet Union (Lewis, 2003). Similarly, a visible decline in population occurred during the early 1980's, as the Siad Barre government grappled with the fallout of a failed Ogaden war and the loss of Soviet support (Lewis, 2003). The other visible decline in population, which occurred during the early 1990's, is likely attributable to the 1992 famine in which around 300,000 people perished (Ó Gráda, 2009). Severe drought and the civil war that erupted when the Siad Barre government collapsed in 1991 are often cited as the root cause of this catastrophe (Ó Gráda, 2009). It's interesting to note that, while the effect of the 1992 famine on the population in Somalia is clearly visible, the effects of the 2011 famine, in which more than 250,000 people perished (Checchi & Robinson, 2013), does not appear to have meaningfully influenced the Somali population curve. Likely this is due to the extreme population growth that took place between these two famines. In 1992, the Somali population was around 7.5 million, by 2011, this number had increased to nearly 12.5 million.

Cereal Production in Somalia since the 1960s

Maize, sorghum, rice, and wheat comprise the only meaningful fractions of Somali cereal production, with maize and sorghum far-and-away dominating the Somali landscape. Total annual production, harvested acreage, and yield data for these cereals are publically available via the Food and Agricultural Organization of the United Nations FAOSTAT website (FAOSTAT, 2017), but seasonal differences in total production, harvested acreage, and yield are not reported. This can be problematic when used to assess food security. Typically, there are two cereal production seasons each year, and annual production figures may mask extreme food shortages that may occur during the lean seasons.

Maize

The Shebelle riverine is Somalia's most important maize producing region (FAO, 2013). Though data regarding specific production practices in the region are scant, most maize in the Shebelle riverine is open-pollinated and grown under furrow irrigation with little to no use of external fertilizers or mechanical implements (Haji, 2017). Traditionally, maize planting populations in the Shebelle riverine are around 35,000 plants ha^{-1} in the Gu season and 29,000 plants ha^{-1} in the Deyr season (Gavin et al., 2018). These practices can be compared to those employed in the Midwestern United States — where farming is highly mechanized, relies heavily on external inputs, and maize planting populations often number near 90,000 plants ha^{-1} (Schnabel & Licht, 2017) — and may help to explain the extreme gulf between Somali maize production figures and those of more developed agricultural environments.

Though the maize yields have been slowly increasing over the last half-century in Somalia, total Somali maize production and harvested area in 2013 were not meaningfully different from the levels observed in 1960 (FAOSTAT, 2017). That is not to say, however, that Somali maize yields, total production, and harvested area have been static since 1960. Rather, each of these factors has been extremely volatile (Figures 2). In the 1960s and 1970s these factors remained relatively constant. Over those two decades, total annual maize production averaged 109,200 t, which was produced on an average of 126,500 ha with an average yield of 872 kg ha^{-1}. In the 1980's, maize yields began to fluctuate, but no positive or negative pattern to this fluctuation is readily discernable. Unlike maize yields, total annual maize production increased dramatically in the 1980's in response to a major increase in maize harvested area. By 1985, the maize area harvested and total annual production had increased by 115% and 154%, respectively, over 1980 levels. These gains may have partially stemmed from the Barre regime's adoption of a National Rural Development Strategy in 1979, which specifically emphasized increasing cereal production (Adam & Ford, 1986). In 1990, 275,000 ha of maize were being harvested; maize yields had increased to over 1,100 kg ha^{-1}, and total maize production had reached 315,000 t.

While these numbers represent considerable improvement over those of the 1960's and 1970's, population growth during this period drastically outpaced growth in agricultural output and resulted in a 1990 per capita maize production of just 42 kg — less than half of what it was in 1961. The disparity was further exacerbated by the collapse of the Somali government in 1991. While maize yields didn't suffer meaningfully in the immediate aftermath of the government's departure, in that first year, the total harvested area of maize was reduced by 63%, and total annual maize production dropped by nearly 70%. These agricultural failings, in concert with the ongoing civil war, would be one contributor to the 1992 famine (Hansch et al., 1994).

Somali maize production has yet to recover from this reduction in harvested area. After bottoming out at just 415 kg ha^{-1} in 1994, maize yields increased gradually in the last two decades. This yield increase, however, has been accompanied by extreme volatility in harvested area, and as a result, has not translated into greater total annual maize production. In 2014, both the total annual production of maize and the total area harvested were actually below 1961 levels. Aberrant data, like the 1994 spike in area harvested or 2000 spike in yield, must be viewed with some skepticism given the difficult research and reporting atmosphere Somalia has faced since the overthrow of the Siad Barre regime.

Of significance in the context of this report are the maize yield, total annual production, and maize area harvested figures leading up to 2011. Probably inconsistent with the present 2011 famine narrative is that maize yields in 2010 and 2011 were amongst the highest in the country's history. The average maize yield in 2010 was 1,500 kg ha^{-1}, and by 2011, that figure had reached nearly 1,800 kg ha^{-1}. Low yields, however, were not the defining feature of this tragedy. Rather, an extremely low total annual maize production of just 65,126 t, the lowest in the country's history, resulted when just 36,382 hectares of land, the fewest in the country's history, were harvested in 2011. This, coupled with consistent population growth, resulted in a total annual maize production per capita of only 5.25 kg in 2011.

Sorghum

Unlike maize, which dominates the irrigated riverine farmland of the Lower Shebelle river, sorghum production in Somalia takes place on the rain fed drylands, and a majority is produced in the central Bay region (Haji, 2017). Since 1961, the total annual production, area harvested, and yield of sorghum have all remained relatively constant in aggregate; however, much like maize, each of these factors has been subject to an extreme amount of year-to-year volatility. This volatility can largely be explained by the aforementioned political and social factors that dictated maize production, but another reason for this unpredictability, specific to sorghum, lies in how it is managed on the Somali landscape. While maize is largely grown under furrow irrigation and only suffers from insufficient water under extreme drought conditions, dryland sorghum is completely dependent on atmospheric moisture for growth, and as such, sorghum yields are highly dependent on timely rainfall and consequently much more variable than maize.

The yield, production, and harvested area of Somali grown sorghum since 1961 mirrors that of maize, but with a greater amount of year-to-year variability owing to sorghum's dependence on atmospheric moisture (Figures 3) (FAOSTAT, 2017). In the 1960's and 1970's, total annual sorghum production, harvested area, and yield remained relatively flat. The average annual production over those two decades was just under 132,000 t, grown on nearly 394,000 hectares of land, with an average yield of 335 kg ha^{-1}. Like with maize production, the adoption of the country's National Rural Development Strategy in 1979 potentiated 1980's sorghum production (Adam & Ford, 1986), which peaked in 1989 at a total annual production level of 333,560 t, produced on 550,000 hectares of land, with an average yield of over 600 kg ha^{-1}.

These gains, however, were short-lived. Similar to that of Somali maize, the collapse of the Somali government in 1991 precipitated a steep decline in sorghum production, and by the end of 1993, the total sorghum area harvested and yield were half what they were in 1989, reducing the total annual sorghum production by more than three quarters (Figure 3). Somali sorghum production has failed to recover in the decades since the Siad Barre regime was overthrown, with sorghum yields remaining flat and total sorghum area harvested fluctuating wildly and trending downward. Extreme data points, like those observed for harvested area in 1994 and yield in 2012, merit some skepticism.

Rice

Relative to the production of maize and sorghum, rice remains a minor cereal crop in Somalia. When it is produced, like maize, the bulk of Somali rice production takes place in the Shebelle riverine region. Here, farmers utilize minimal external inputs and employ a system of furrow irrigation, while managing their crop (Haji, 2017). Though the intricacies of Somali rice production remain significantly under investigated, publically available data describing the yield, total production, and area harvested of Somali rice since the 1970's demonstrate similarly volatile relationships to those observed for maize and sorghum (Figures 4).

While maize and sorghum yields remained relatively flat during the 1970's, rice yields rapidly declined towards the end of the decade. They reached their lowest point in 1978, when the average rice yield was just 1,163 kg ha^{-1}. However, during this time, total rice production increased steadily and rose sharply towards the end of the decade due to an extremely steep increase in harvested area that took place during this time and peaked in 1978 at 9,800 hectares.

Yields recovered in the 1980's, likely as a result of the aforementioned adoption of a National Rural Development Strategy, and peaked at 4,076 kg ha^{-1} in 1985. These yield increases mirrored those observed for maize and sorghum during this time, but while those yield increases resulted in an overall increase in total production for both crops, total overall rice production fluctuated wildly in the 1980's owing to extreme variability in the annual rice area harvested. From 1982 to 1983, total overall rice production fell by 79% in response to an 83% drop in harvested area, but by 1989, the rice area harvested had increased to 6,500 hectares, a gain of 550% from the 1983 level, and total rice production had rebounded by over 400% to 19,700 t.

As stated above, the 1990's were an extremely turbulent decade for Somali crop production, and rice was no exception. While the total production of both maize and sorghum fell substantially between 1991 and 1992, total rice production actually increased by 50% in that time due to an increase in harvest area increase, which offset sluggish yields in the early half of the decade. This increase, however, was not enough to compensate for the productive losses of maize and sorghum and would have had a negligible effect on preventing the 1992 famine. These gains also proved short-lived. Within three years of the Somali government's collapse, total Somali rice production had declined by 84%, bottoming out at just 1650 t and stayed relatively static rest of the decade. This decline and stagnation was largely due to a major reduction in area harvested that began in 1993 and has yet to recover.

Total rice production increased dramatically during the first decade of the new millennium, but by 2014, it collapsed to just 600 t — the lowest level in recorded history. As the harvested rice area has remained relatively flat since the early 2000's, these productive gains and losses are wholly attributable to yield fluctuations. In 2010, the average rice yield was 5,200 kg ha^{-1} and total production levels were around 8,500 t. By 2011, rice yields had dropped by nearly a third and total production had declined by 50%. Compared to maize and sorghum, rice production makes up an extremely small fraction of domestic cereal production in Somalia (less than 4% on average since 1960) and these productive declines would not have would not have precipitated the 2011 famine, however, they may have exacerbated an already taxed food system.

Wheat

While wheat occupies more of the world's cropland than any other species (Leff et al., 2004), its presence on the Somali landscape is negligible compared with the footprints of maize, sorghum, and even rice. Unlike Somalia's other cereal crops, however, wheat has proven to be one of the country's most predictable food crops in terms of total production, yield, and harvested area (Figure 5). Though wheat was once envisioned as a short-season, irrigated, lowland crop (Tanner & Van Ginkel, 1988), the majority of Somali wheat production today takes place in northern Somalia's dryland region with minimal use of external fertility and little to no mechanization (Haji, 2017).

At one point, it was estimated that irrigated wheat might come to occupy as many as 40,000 hectares of land in southern Somalia (Tanner & Van Ginkel, 1988), but this level of production has never been realized. Rather, the harvested area of Somali wheat rose sharply between 1970 and 1974 before flattening out and peaking at just 3,800 hectares in 1989. During this period, concerted efforts to determine best agronomic practices and improve the country's available germplasm were underway (Tanner & Van

Ginkel, 1988), but as the power of the Siad Barre regime diminished, so too did international efforts to improve Somali wheat production, and between 1989 and 1991 the wheat harvested area declined by 52% resulting in a 53% drop in total wheat production and reaching an historic low production level of just 660 t. Since this decline, however, the wheat area harvested has remained relatively flat and yields have been steadily increasing. Thus, total wheat production in Somalia over the last two decades has been reliable. In fact, total wheat production did not appear to suffer at all during either the 1992 or 2011 famine years.

Per Capita Cereal Production and People Per Harvested Hectare

When these agricultural data are related to the abovementioned population data, a clear trend emerges; per capita cereal production in Somalia has declined precipitously over the last half century. While yields have remained flat or slightly improved in that time, each harvested hectare of cereal was required to support nearly seven and a half times more people in 2014 than it was in 1961 (Figure 6.). Even during the relatively productive years of the 1980's, the gains in agricultural output failed to match those of population growth, and per capita production never reached the level observed in the early 1960's.

Of particular interest in the context of this paper is per capita production during the 1992 and 2011 famine years. During the 1992 famine, per capita cereal production in Somalia was just under 28 kg per year. By 2011, this number had crashed to an historic low of less than 10 kg. While these numbers are dramatic, it is important to put them in context. Since 1992, the average annual cereal production per capita has been just 31 kg. In the last fifty years, cereal grains have provided anywhere from a third to half of a Somali's average daily caloric intake (National Geographic Magazine, 2017). At around 3500 kcal kg^{-1} of cereal grain (Cleveland, 2013), and assuming a 2000 kcal per day diet and equal distribution of grain, this level of production could only support the Somali population's needs for four to six months. This means that domestic cereal production has not been a major determinate of famine within Somalia's borders since the collapse of the Siad Barre regime. The country has become nearly completely dependent on extra-territorially produced foodstuffs — either imported for purchase or donated as food aid — and famine in Somalia cannot be solely attributable to the fluctuations in domestic production which result from short-term, extreme weather events like drought.

Food Imports and Aid

Food imports and aid are completely distinct from each other. Food imports are extra-territorially produced foodstuffs that are brought into a country to be sold in the marketplace at market value. In contrast, food aid can be described as foodstuffs that are supplied to a population at no or reduced cost or in food-for-work or food-for-education schemes. In the face of declining domestic per capita production, food imports and aid have become essential contributors to the available food supply in Somalia.

Data regarding the importation of food into Somalia is available via the FAOSTAT website dating back to the early 1960's. Since that time, Somali food imports have risen steadily — both in real and per capita terms (Figure 7). In 1961, total food imports into Somalia were just over 42,000 t. In 2013, this number had increased to over 990,000 t. Similarly, in that same timeframe, Somali per capita food imports rose from 15 kg per person to 75 kg per person — an increase of more than 400%. Over this same timeframe, the population of Somalia increased by Approximately 367%.

While many crops are imported annually, the combined total of the aforementioned cereals — maize, sorghum, rice, wheat, and their processed derivatives — make up the greatest portion of total food imports. On average, these cereals constitute a little over half of all food imported (FAOSTAT, 2017). The importance of imported cereals was especially profound in the 1980's when these four cereals made up 75% of all food imports. Like total food imports, total cereal imports have tended to increase over time, but no obvious trends exist which distinguish their relative importance annually. Rather, maize, wheat, and sorghum imports have varied radically from year to year. Global prices, import availability, and to a lesser extent local demand, are likely responsible for this variability. Rice imports seem to be an exception to this rule, as annual rice importation has increased steadily in the last 50 years (Figure 8).

Of most consequence in terms of issues concerning food sovereignty and security is the ratio of domestic food production to food imports. In the 1960's and 70's the average ratio of Somali-grown cereals to imported cereals was 8.5 to 1.0. By the end of the 1980's, this ratio had halved, and since the fall of the Siad Barre regime in 1991, it has halved again. It is important to recognize these relative contributions when discussing the influence of food imports on famine.

In 1992, the ratio of Somalia-grown cereals to imported cereals was just 0.68 to 1.0. In 2011, this ratio was even lower at 0.36 to 1.0. In 1992, cereal production plummeted from a three-year average of near 500,000 t to just over 200,000 t, and during that time, food imports remained relatively flat. In contrast, when famine arose again in 2011, a nearly identical 57% decrease in domestic production was exacerbated by an average decline in food imports of 37% annually, over the previous three years —and this took place at a time when food imports had become increasingly important. It is reasonable to conclude, therefore, that while a failure of domestic production limited the availability of foodstuffs in 1992, a rapid decline in food imports was a major driver of the 2011 Somali famine.

In the context of Somalia, food aid must also be discussed as being a major contributor to the country's overall available food. The principle providers of food aid into the country are the World Food Program (WFP), the International Committee of the Red Cross (ICRC), and CARE international (CARE), with the vast majority of food aid coming from the United States (Maxwell & Fitzpatricks, 2012). Data on food aid transfers into Somalia date back to 1988 and are available via the World Food Programme's Food Aid Information System. These data are, at times, incomplete and should be viewed with a degree of incredulity, but in aggregate, the dataset is probably the most complete publically available source and has been utilized for the sake of these analyses.

Like was the case with food imports, food aid in the form of cereals or their processed derivatives comprises the great majority of food aid being delivered to Somalia and was the focus of this examination (WFP, 2017). The amount of cereal aid being sent to Somalia has varied from year to year, though at no point since 1988 (when publically available data became available) has Somalia been free of cereal aid (Figure 9). Cereal aid decreased in the four years leading up to the collapse of the Siad Barre government. This likely resulted from a combination of reduced dependence on the part of Somalis who, as previously mentioned, had managed to dramatically increase domestic cereal production in the 1980's, and a reduced incentive on the part of the United States to support the Siad Barre regime (Lewis, 2003). With the advent of famine in 1992, cereal aid into Somalia increased by over 200% reaching a peak aid level of nearly 220,000 t. Following the 1992 famine, a steady decrease in cereal aid resulted in Somalia's lowest recorded level of just 4,500 t in 1997. This relatively low level of cereal aid would be maintained for nearly a decade before beginning a dramatic increase in 2005. By 2008, in just three years, cereal aid into Somalia had climbed 972%. This support, however, did not last long. In just two years, aid was reduced by two-thirds, and in 2011, a state of famine was declared. Undoubtedly, this rapid decline in aid, coupled with the aforementioned reduction in food imports, would have sent shockwaves through a food system heavily dependent on extra-territorially produced foodstuffs and contributed to precipitating the 2011 famine.

Total Cereal Availability

Somali cereal production, imports, and aid make up the major fractions of the Somali cereal supply, and their sum can be considered the measure of total available cereal in the country at a given time. While cereal exports would normally merit consideration, Somali cereal exports are nearly nonexistent, and data attributing any meaningful value to them would certainly be suspect. As mentioned above, in real terms, total Somali cereal production has been volatile and remained relatively flat since the 1960's; cereal imports have increased steadily since that time; and cereal aid has been unpredictable since the late 1980's. In per capita terms, cereal production has fallen dramatically since the 1960's; cereal imports have increased in that time; and no discernable pattern to cereal aid since the 1980's has been observed.

In real terms, total available cereal in the country has trended upwards over time, but in per capita terms, total cereal availability has been highly erratic and remained relatively flat since the 1960's (Figure 10). Interestingly, the five years with the lowest per capita cereal availability were not officially declared famine years; however, in both famine years, cereal availability rose and then fall dramatically in the preceding years. This may be an indication that, while absolute cereal availability is hugely determinate of food security, year-to-year volatility is of greater significance.

In 1992, the cause of this volatility can be identified fairly simply. In the late 1980's, domestic cereal production had reached historic levels; cereal imports had diminished in importance and quantity; and cereal aid had begun to decline. Then, with the collapse of the Siad Barre regime, the country was thrown into chaos, civil war erupted, and drought struck. This caused domestic cereal production to plummet, and the imports and aid, which had been declining, could not increase rapidly enough to compensate for the productive shortcomings.

In 2011, the instability is more difficult to explain. In 2003, domestic cereal production began to decline, and in 2007, it reached its lowest level in a decade at just 52 kg per capita. However, as a result of dramatic increases in cereal imports and aid beginning in 2005, the total available cereal in 2007 was only 16% below that of the previous five-year average, and famine may have been successfully averted. Cereal imports had likely been increasing because the decline in domestic production leading up to 2007 had been fairly gradual, and the massive increase in aid was probably in response to a combination of the aforementioned decreasing domestic cereal production and increasing civil and political unrest. This meant, however, that Somali food security was completely dependent on externally produced foodstuffs.

This dependence would prove disastrous. In December 2006, Ethiopian troops invaded and overthrew the Islamic Courts Union (ICU), which had been governing Mogadishu. They occupied the Somali capital for two years before being replaced by African Union forces in 2009. In 2010, the African Union soldiers were routed from the city by al Shabaab, and in order to exert pressure on the terror group, the United States halted aid to Somalia (Menkhaus, 2012). All told, between 2008 and 2010, cereal aid bound for Somalia dropped 66%. When combined with the abovementioned rapid drop in food imports that occurred during those same years, Somalia's food security situation became extremely precarious. Finally, after drought resulted in consecutive Deyr and Gu season crop failures (Ferris & Petz, 2012), the United Nations officially declared a state of famine in Somalia on the 18th of July 2011. In 2011, total cereal availability was nearly 30% lower than the previous five-year average — almost twice the relative drop in cereal availability observed in 2007. Even though total cereal availability in 2007 was lower in absolute terms, famine occurred in 2011.

Conclusion

The Somali food security situation is incredibly complex. As the importance of domestic production waned over the last quarter century, the relative importance of cereal imports and aid rose. This left the country's food security situation extremely vulnerable to disruptions in the supply of extra-territorially produced foodstuffs. As such, while numerous articles reference the contribution that domestic production failures made to the 2011 famine (Ferris & Petz, 2012; Haan et al., 2012; Majid & McDowell, 2012; Menkhaus, 2012), it is also important to recognize the role that domestic and external actors and policymakers play in maintaining Somali food security. One way to mitigate the risk of dependence on foreign foodstuffs would be for Somalia to increase domestic cereal production. It has already been demonstrated that drastic increases in Somali maize yields are possible through relatively simple improvements in agricultural management practices (Gavin et al., 2018), but to do so on any meaningful scale will require significant investments in security and internal infrastructure.

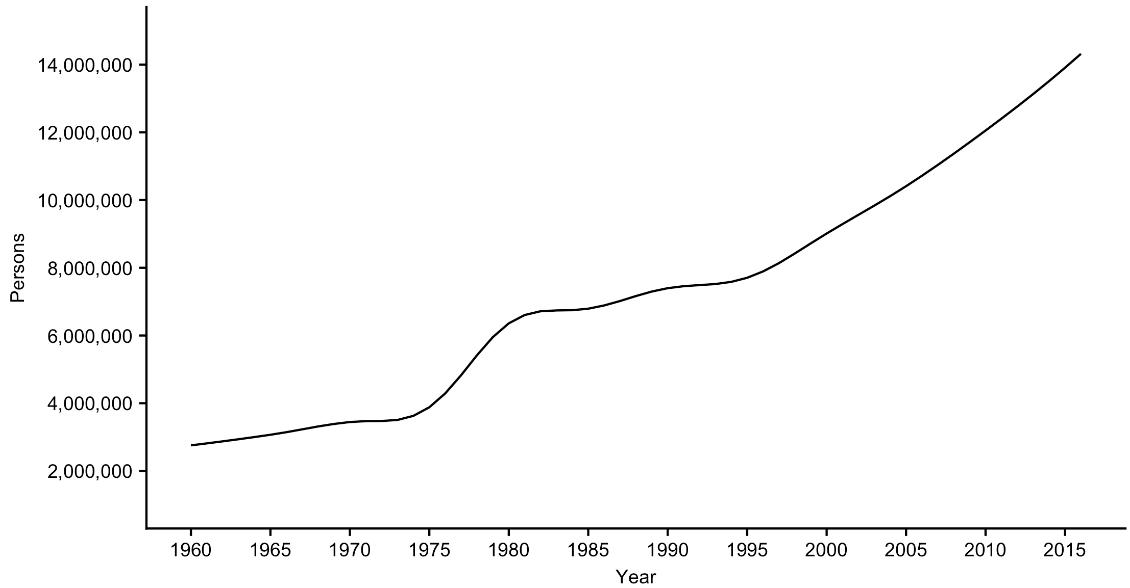

Figure 1. Somali population over time.

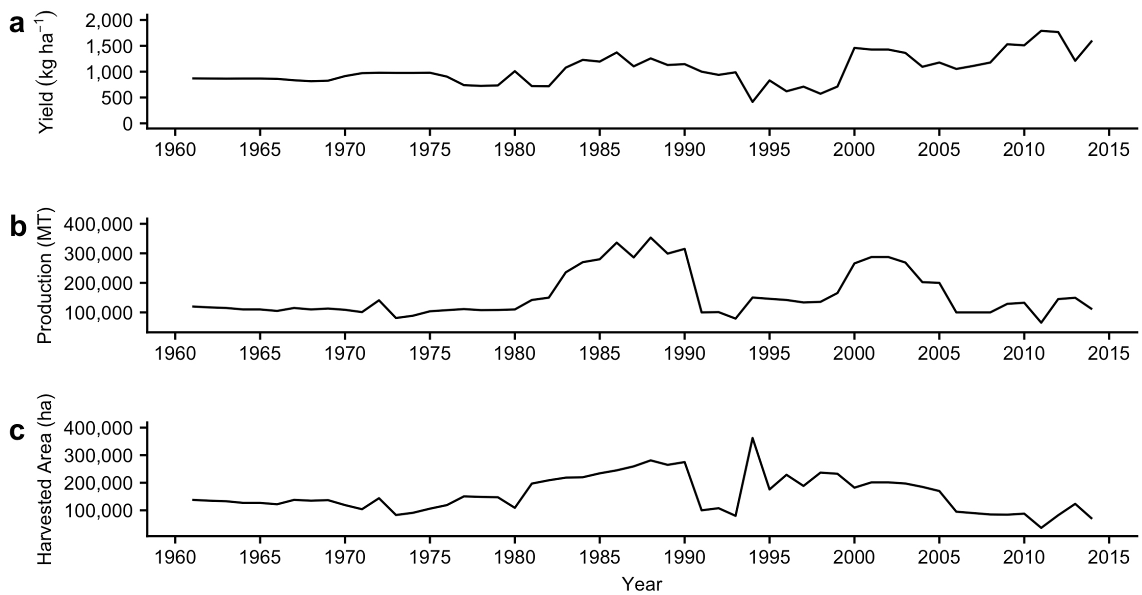

Figure 2. Average annual yield (a), production (b), and harvested area (c) of Somali maize.

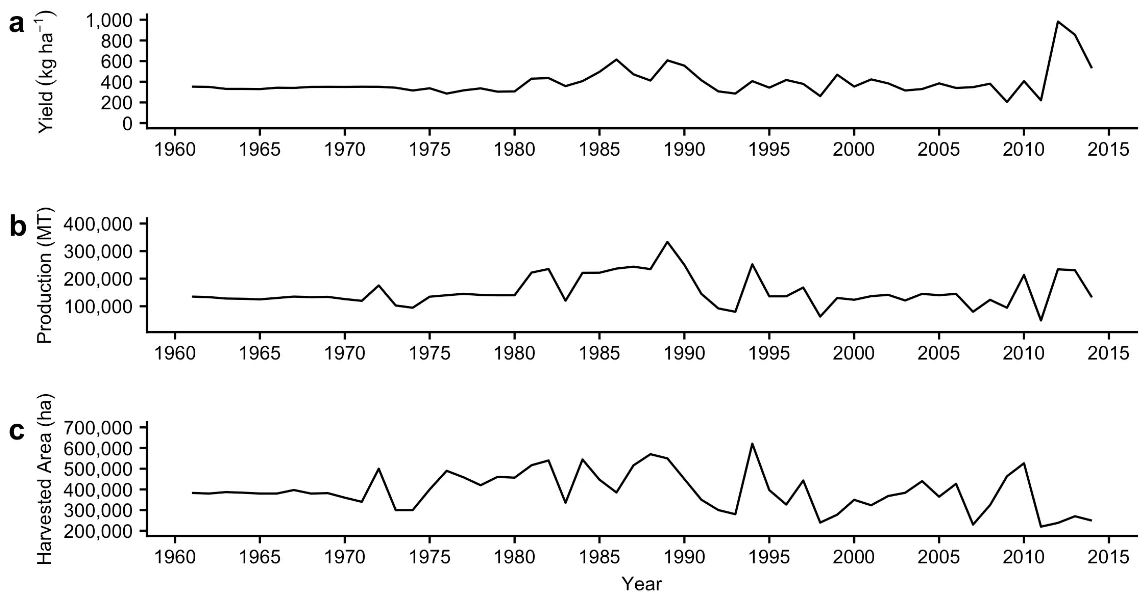

Figure 3. Average annual yield (a), production (b), and harvested area (c) of Somali sorghum.

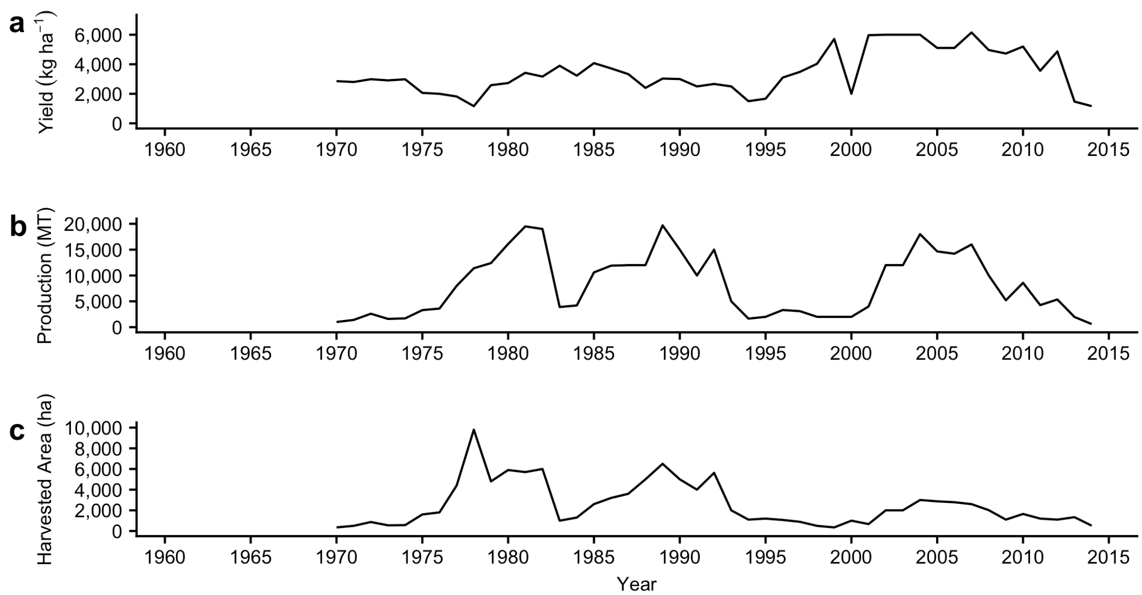

Figure 4. Average yield (a), production (b), and harvested area (c) of Somali rice.

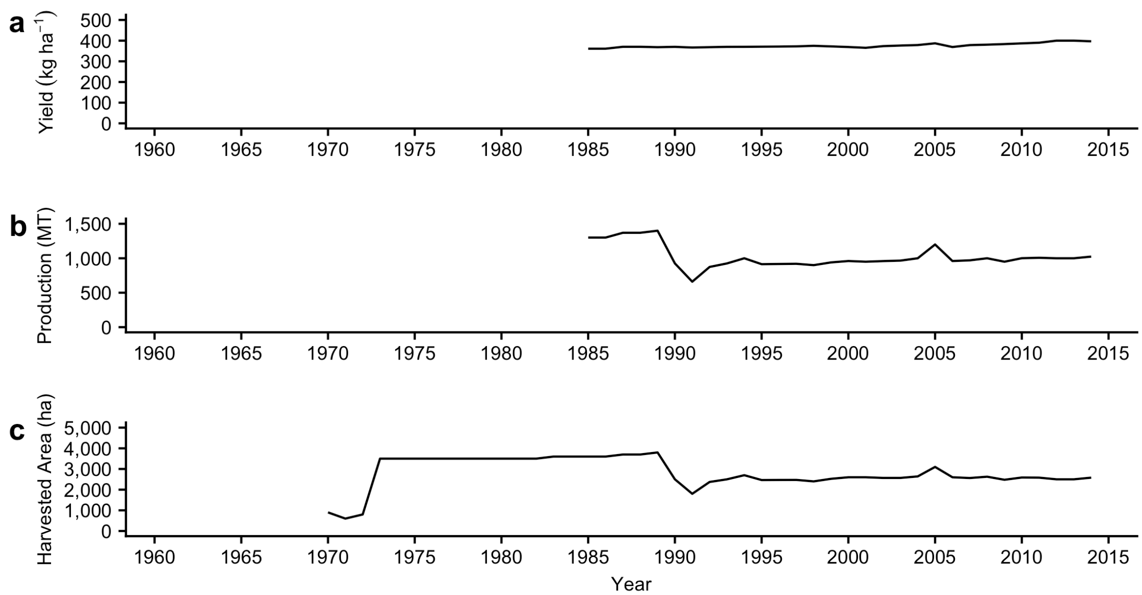

Figure 5. Average yield (a), production (b), and harvested area (c) of Somali wheat.

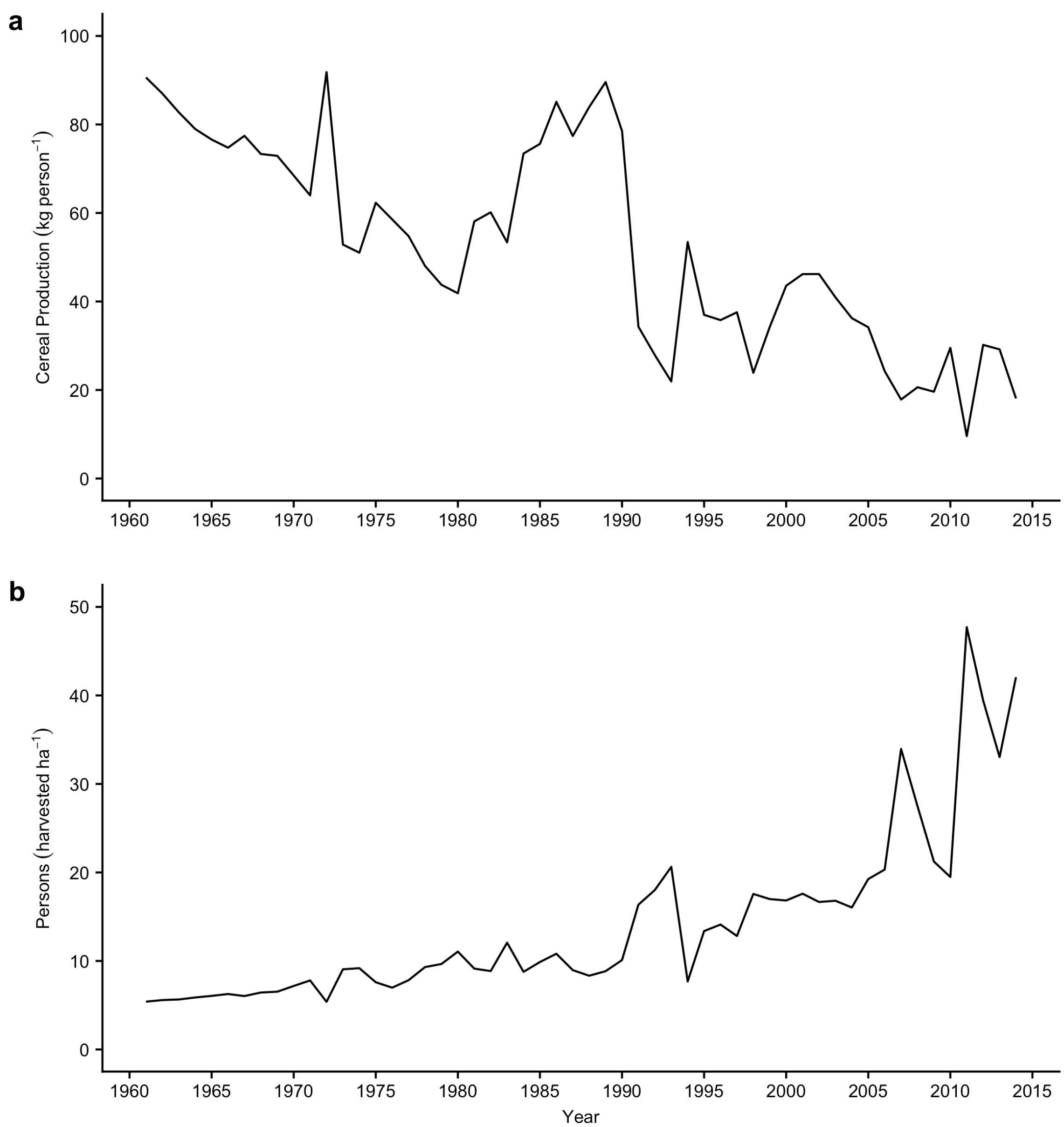

Figure 6. Total annual cereal production per capita (a) and number of people per harvested cereal hectare (b).

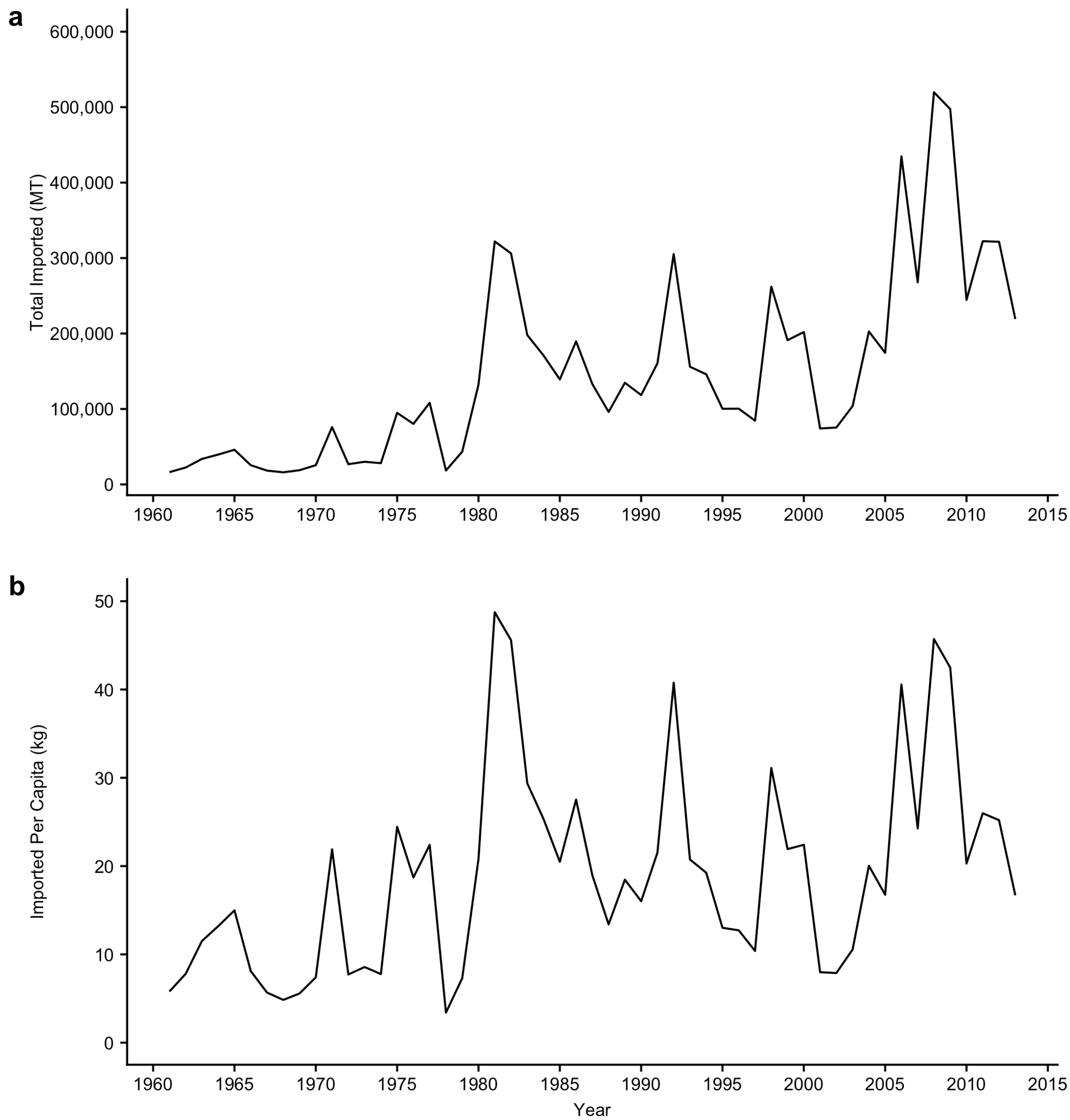

Figure 7. Total annual imported cereal in real (a) and per capita (b) terms.

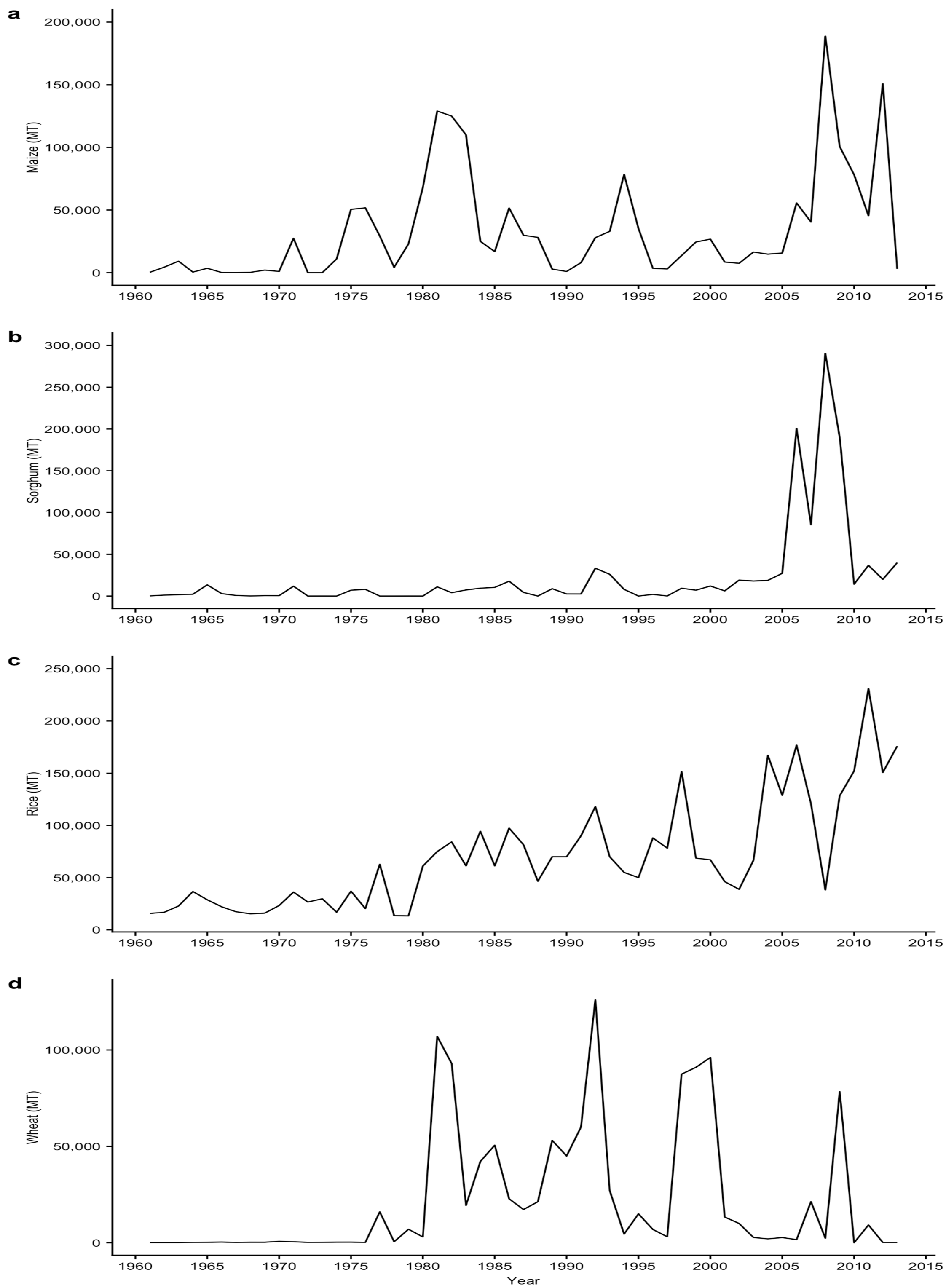

Figure 8. Total annual imports of maize (a), sorghum (b), rice (c), and wheat (d) over time.

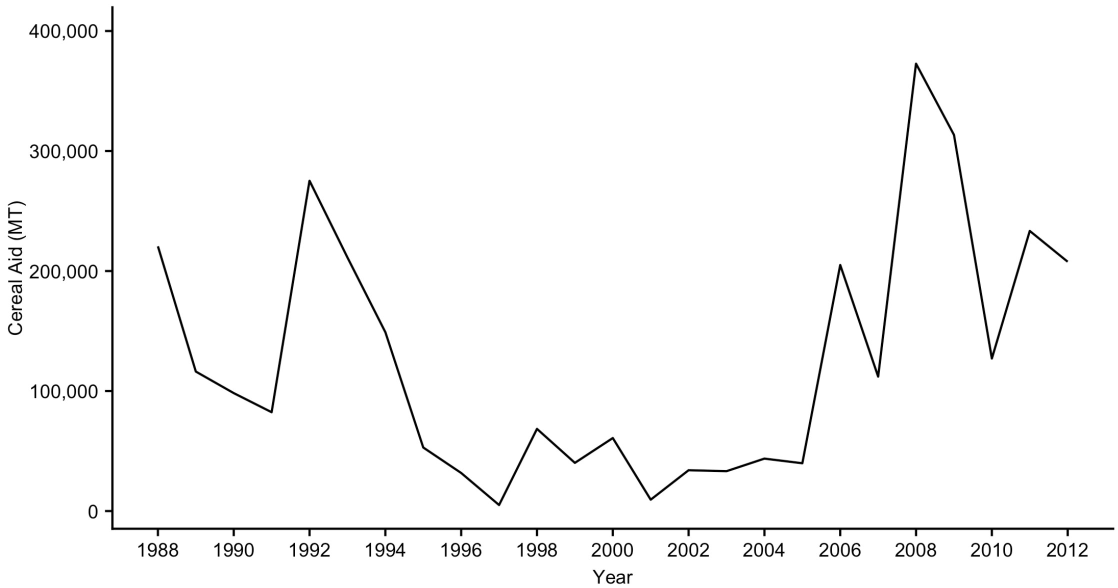

Figure 9. Annual cereal aid deliveries to Somalia.

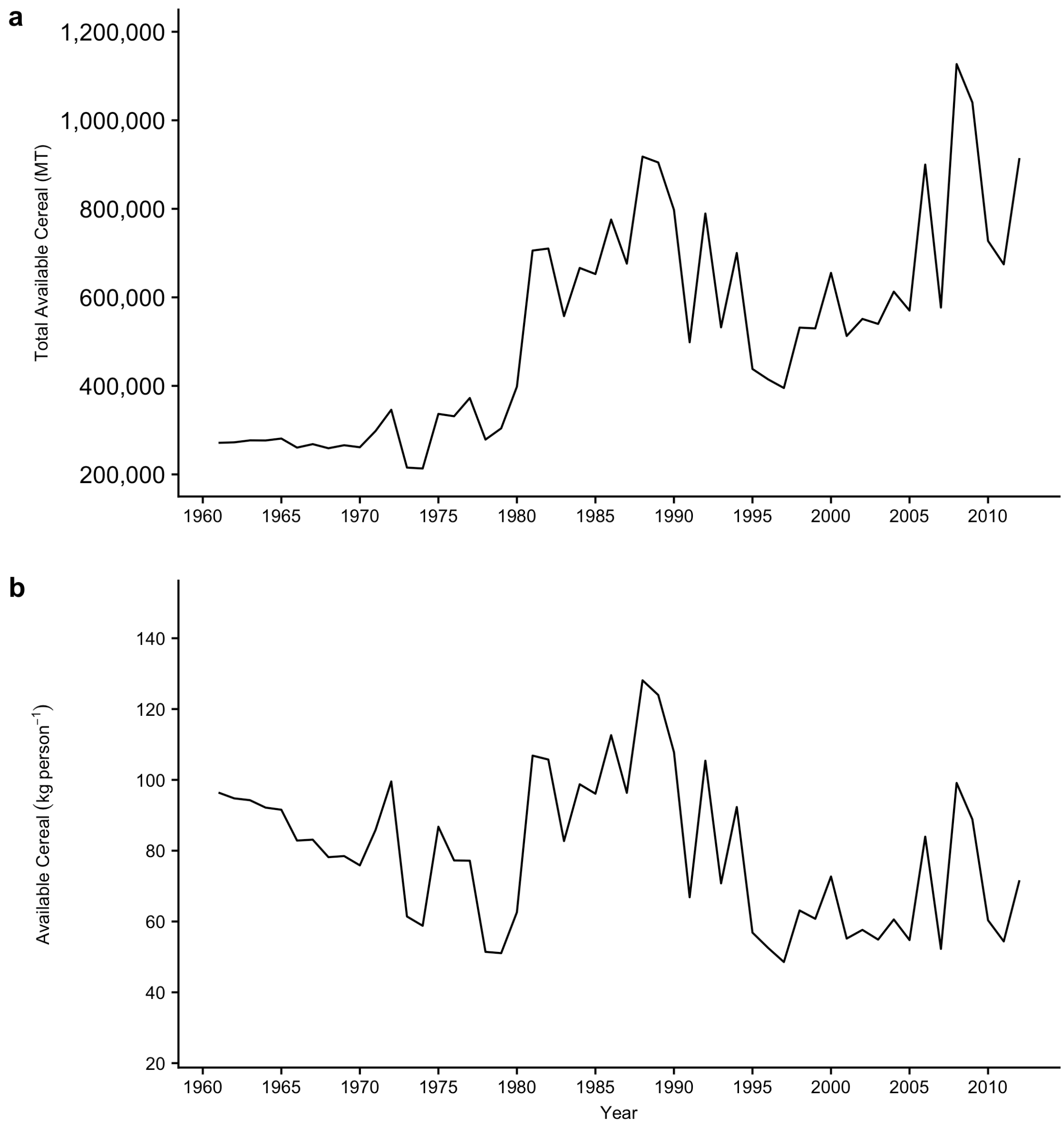

Figure 10. Total available cereal (domestic production, imports, and aid) in real (a) and per capita (b) terms.

Chapter 2

On-farm Irrigated Maize Production in the 2014 Somali Gu Season

Summary

Somalia faces perennial insecurity, and less than half of the population's cereal requirements are currently satisfied by domestic production. 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 followed simple best management practices (BMPs) recommended by SATG like mineral nitrogen and phosphorus fertilizers, the pesticide Bulldock® (Beta-Cyfluthrin), and an elevated planting population. This SATG system was also compared to a Zero system, which received the same management practices less mineral nitrogen, and a traditional farming system, which did not utilize mineral fertilizers or apply pesticides and had a low, unspecified planting population. This research was conducted on eighty-one farms located near the villages of Afgoi and Awdhegle. In the 2014 Gu season, the method of nitrogen application did not significantly influence grain yields, stover yields, or plant heights, but the SATG system (the average of the Broadcast, Hill, and Row treatments) was found to have greater grain yields, stover yields, and plant heights than both the zero and traditional systems. Significant location by treatment interactions ($P < .05$) were observed for grain yields and plant heights but not for stover yields, the data for which were suspect in this trial. On farms located near Afgoi, the grain yield of the improved SATG system (3531 kg ha^{-1}) was 48% greater than that of the Zero system and 64% greater than that of the traditional system. Near Awdhegle, these values were 56% and 73%, respectively (SATG = 5325 kg ha^{-1}). The average harvested plant populations of

the improved systems (SATG and Zero system = 46198 plants ha^{-1}) were 23% greater than those of the traditional system on farms near Afgoi and 59% (SATG and Zero system = 51479 plants ha^{-1}) greater on farms near Awdhegle. Plants were consistently taller on farms near Awdhegle than they were on farms near Afgoi. These locational differences can likely be attributed to differing farm management practices and soil properties like electrical conductivity (EC), which exist between these two locations. These data demonstrate that, by utilizing the simple BMPs prescribed by SATG, Somali farmers can dramatically increase maize yields in the Lower Shebelle.

Introduction

Somalia is one of the poorest countries on the planet. The east African nation has been plagued by prolonged civil unrest and an extremely volatile environment, which has 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 around 50% of the population's cereal 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 (FAOSTAT, 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, funded by the United States Agency for International Development (USAID) under the Partnership for Economic Growth (PEG) initiative, SATG utilized an on-farm participatory research approach to compare their recommended BMPs with the traditional farming practices in 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) and was thought to be capable of seeing dramatic yield increases through the implementation of a few low-tech agronomic BMPs.

These 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 & 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 (Haji, 2017). 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), it is not common practice in the irrigated maize production systems of the Lower Shebelle (Haji, 2017).

There were two objectives of the 2014 Gu season research trial. The first objective was to examine whether different methods of nitrogen fertilizer application had an effect on irrigated maize that was managed using SATG BMPs. The second objective was to compare these improved systems to the traditional production system currently employed by maize farmers in the region.

Materials and Methods

During the 2014 Gu season, a participatory on-farm research trial was conducted by SATG in the Lower Shebelle region of Somalia. 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 sees temperatures that range from 27 to 31 degrees Celsius (Ali, 1988). 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 250 to 300 mm of rainfall during the Gu season; however, it should be noted that in 2014 the Gu 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 Vertisol soil type is characterized by 2:1 clays, smectitic mineralogy, a high cation exchange capacity, and shrink-swell properties.

This trial was unique for its size and participatory nature, 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 agents to oversee the management, harvest, and data collection of the research plots on their land.

With knowledge extension at the forefront, this research trial was designed to be a relatively simple multi-location randomized complete block (RCB) experiment in which each participating farmer planted five treatments on their land. The five treatments included: three SATG treatments, one zero treatment, and one traditional treatment. To achieve this, each participating farmer donated one jibaal (625 m^2) of land to SATG and managed the balance of their land using their own traditional practices. The donated jibaal was subdivided into four 10 m^2 plots, with each subdivisions housing one of the three SATG treatments or the zero treatment. The traditional treatment was evaluated on the farmland adjacent to each SATG jibaal and was managed using the farmers' normal cultural practices.

For data collection, two 3m^2 areas of each treatment plot were subsampled and their plant and sample data were averaged. The three SATG treatments and the zero treatment were managed using the BMPs designed by SATG, while the traditional treatment was managed according to each participating farmer's cultural practices. A major component of the SATG BMPs system included supplemental fertility. The added fertility consisted of two applications of urea 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 method of urea application was a factor of interest in this trial, and delineated the three SATG treatments. For these treatments, urea was applied using one of three different techniques: a row application, a hill application, and a broadcast application. 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; the hill application was performed by applying urea to a small hole that had been dug next to each individual maize plant; and finally, the broadcast application was performed by evenly applying urea over the entire planting area and then incorporating the urea via a hand hoe.

In the case of the three SATG treatments, the first of the urea applications took place at planting and the second occurred when the maize was near the V4 growth stage. In the case of the zero treatment, no urea nitrogen was applied at all. In addition to added fertility, the SATG BMPs system also called for an application of the insecticide Bulldock® (Beta-Cyfluthrin) at a rate 5.0 kg ha^{-1} in order to control spotted stem borer (*Chilo partellus*), and a relatively high planting population. The desired planting population for the SATG BMPs system was 53,333 plants ha^{-1}, with a between row plant spacing of 0.75 meters and a within row plant spacing of 0.25 meters. No set planting population was defined for the traditional treatment. The SATG system also required timely weeding and irrigation events, while the traditional system land was weeded and irrigated according to the cultural practices of each participating farmer. All five treatments were planted with the same locally-available, open-pollinated maize variety, "Somtux".

The main parameters of interest in this study consisted of plant yield and growth components. Grain and stover yield data were obtained by harvesting the respective plant portions and air drying the material. Grain moisture was obtained via 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, harvested plant population, and harvested cob population measurements were determined at harvest. The precision of plant height, grain yield, and stover yield measurements was limited by technologic availability. Plant height measurements were taken to the nearest tenth of a centimeter and grain and stover yields were recorded to the nearest half kilogram. The lack of precision in grain and stover yield measurements likely contributed to the high standard deviations observed in this trial.

Data from the experiment were analyzed 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 ($P < 0.05$) of our independent variables and Tukey's HSD test was used for mean separation (Table 1). For the ANOVA analysis, 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 is 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 farms participating in this trial, and within a 10km radius of the experiment stations. This compiled dataset contained pH (1:1 soil/water), electrical conductivity, cation exchange capacity, and texture (sand and clay proportions) for 8 locations (4 at Awdhegle and 4 at Afgoi).

Results and Discussion

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 (Table 1). Significant treatment by location interactions were observed for grain yield, stover yield, harvested plant population, and harvested cob population. Though these interactions were significant, the interpretation of the data from each of these locations was consistent: in each location, the broadcast, hill, and row treatments (heretofore referred to as the three SATG treatments) did not vary significantly with one another but did demonstrate significantly higher grain yields, stover yields, and harvested cob populations than the zero and traditional treatments (Table 1). The three SATG treatments also had significantly greater harvested plant populations than the traditional treatment, though they were not significantly different from the zero treatment. This is unsurprising given that the zero treatment only differed from the three SATG treatments in that no urea was applied to it. Like the three SATG treatments, the zero treatment also performed better than the traditional treatment for each of the aforementioned parameters of interest.

The treatment by location interactions that were observed for grain yield, stover yield, and harvested cob population were the result of differing effect magnitudes between treatments at each location, rather than inconsistencies related to treatment effectiveness. These differing treatment effect magnitudes likely resulted from differences in each location's underlying soil characteristics, which will be discussed in greater detail below, and the significant differences in harvested plant populations that were observed between the locations.

No significant difference between the three SATG treatments was observed at either location (Table 1). In Afgoi, the average yield of these three SATG treatments (3531 kg ha^{-1}) was 48% and 64% greater than that of the zero and traditional treatments, respectively. In Awdhegle, the average of these treatments (5325 kg ha^{-1}) yielded 56% more grain than the zero treatment and 73% more grain than the traditional treatment. Grain yields in Awdhegle (4492 kg ha^{-1}) were 49% higher than those observed in Afgoi. Interestingly, anecdotal evidence from the region suggests that farmers near Awdhegle are believed to be better and more skilled than those near Afgoi (Haji, 2017). Though these data seem to support that belief, underlying chemical and physical soil properties could also be major drivers of these locational grain yield differences.

Though scarce, the soils data available from the region 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 cmolc/kg) 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, electrical conductivity (EC) and sand proportions did appear to differ significantly between locations. EC values near Afgoi were an order of magnitude higher than EC values near Awdhegle (9.1 ± 6.8 dS/m and 0.5 ± 0.2 dS/m, respectively, $p < 0.05$, unpaired T-Test), and sand percentages were approximately 2-3 times higher near Afgoi (17 ± 6%) compared to Awdhegle (5 ± 4%) ($p < 0.05$, unpaired T-Test) (data not shown).

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 important enough to explain the observed differences in yield. However, the strong differences in EC could certainly be enough to explain at least some of the observed differences in crop growth and yield between the two locations.

Stover yields in the 2014 Gu season must be viewed with some skepticism because the stover was air dried and weight measurements were not standardized to a specific moisture content. Consequently, the statistical analysis of these yields is also suspect. 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 (11954 kg ha^{-1}) were 10% greater than that of the zero treatment and 34% greater than that of the traditional treatment. In Awdhegle, stover yields were 12819 kg ha^{-1}, and these differences were 26% and 63%, respectively. No meaningful differences in overall stover yields between the two locations were observed. This was interesting given the greater harvested plant population observed at Awdhegle, and suggests more moisture laden or poorly dried plants in Afgoi. The treatment differences observed for stover yield are unsurprising. The increased stover yields observed with the three SATG treatments and the zero treatment are undoubtedly a consequence of the increased fertility and plant populations recommended by SATG.

Plant populations at harvest between the three SATG treatments and the zero treatment were not meaningfully different from each other at either location, though the average harvested plant population of these treatments at Awdhegle (51479 plants ha^{-1}) was 11% greater than at Afgoi. 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 (46198 plants ha^{-1}) was 23% greater than the traditional treatment. In Awdhegle (51479 plants ha^{-1}), they were 58% greater. Interestingly, unlike the three SATG and zero treatments, the harvested plant population of the traditional treatment in Awdhegle (32542 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 (3075 kg ha^{-1}) was 43% greater than in Afgoi. This further bolsters the argument that the abovementioned underlying soil characteristics near Awdhegle are more favorable than those near Afgoi and are the drivers of the observed locational differences in grain yield.

As one would expect, the data regarding the number of cobs harvested from each treatment closely mirrors that of the harvested plant population data. In both locations, more cobs were harvested from the three SATG treatments than the zero treatment and more cobs were harvested from the zero treatment than the traditional treatment. In Afgoi, the average of the three SATG treatments (44069 cobs ha^{-1}) produced 7% more harvestable cobs than the zero treatment and 29% more than the traditional treatment. In Awdhegle, where the harvested cob population of the three SATG treatments was 52500 cobs ha^{-1}, these differences were 14% and 63%, respectively. It was interesting that a significant difference between the number of harvested cobs for the three SATG and zero treatments was identified, but that this difference was not observed in their harvested plant populations. This could suggest that the added nitrogen fertility of the three SATG treatments was useful for ensuring grain fill.

Unlike the grain yields, stover yields, and the number of harvestable cobs, no interaction between treatment and location was observed for plant heights, though significant treatment and location differences were observed. Plant heights at Awdhegle, which averaged 179 cm tall, 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. These height differences are likely the combined result of greater planting densities, which lead to increased plant heights (Tetio-Kagho & Gardner, 1988) and increased soil fertility.

With eighty different observations of each of the five treatments, this experimental design also allowed simple regression analyses on the relationships that existed between grain yield, plant height, harvested plant population, and 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 suggested that planting date wasn't 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 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 plants.

A significant positive relationship between grain yield and harvested plant population 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 was 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 in this analysis suggest that increasing planting populations will result 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 (.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 plant height and harvested plant population 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 steepest relationship. This is in keeping with previous research, which demonstrated a relationship between planting population and plant height (Tetio-Kagho & Gardner, 1988). When grain yield and plant height were compared, 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.). This relationship, however, may simply result from the fact that a field with taller plants may have had a higher harvested plant population.

Conclusion

Since the collapse of the Siad Barre government in 1991, Somalia has been mired in conflict and political instability. As a result, there are major deficiencies in even the most basic agronomic research. In the 2014 Gu season, the Somali Agriculture and Technical Group (SATG) sought to address some of these deficiencies through targeted maize cropping system research. In this study, the implementation of SATG BMPs resulted in maize grain yields (4428 kg ha^{-1}) that were 70% greater than that of the traditional farming system employed in the region, with the greatest grain yields being observed at the highest harvested plant populations and at the earliest planting dates. This work demonstrated that soil fertility, especially nitrogen availability, was the primary driver of grain yields in the Lower Shebelle region during the 2014 Gu season, but that the 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.

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.

Treatment	Location	Grain Yield kg ha^{-1}	Stover Yield Kg ha^{-1}	Harvested Plant Pop. ha^{-1}	Plant Height cm	Harvested Cob Pop. ha^{-1}
Broadcast	Afgoi	3500	12100	46917	162	43833
Hill	Afgoi	3637	11567	45750	163	44292
Row	Afgoi	3456	12196	45667	164	44083
Zero	Afgoi	2384	10894	46458	156	41250
Traditional	Afgoi	2149	8932	37667	145	34083
Broadcast	Awdhegle	5392	12646	51750	182	51667
Hill	Awdhegle	5434	13042	52208	187	54042
Row	Awdhegle	5149	12771	51375	182	51792
Zero	Awdhegle	3413	10146	50583	176	45958
Traditional	Awdhegle	3075	7875	32542	169	32250
Broadcast	—	4446 a	12373 a	49333 a	172 a	47750 a
Hill	—	4535 a	12304 a	48979 a	175 a	49167 a
Row	—	4303 a	12483 a	48521 a	173 a	47938 a
Zero	—	2898 b	10520 b	48521 a	166 b	43604 b
Traditional	—	2612 b	8403 c	35104 b	157 c	33167 c
—	Afgoi	3025 B	11138 A	44492 B	158 B	41508 B
—	Awdhegle	4492 A	11296 A	47692 A	179 A	47142 A
HSD (Treatment)		370	1228	2341	5	2725
HSD (Location)		168	557	1062	2	1236
R^2		0.77	0.72	0.71	0.76	0.7
CV(%)		22.7	25.2	11.7	6.7	14.2
Treatment (P>f)		<.0001	<.0001	<.0001	<.0001	<.0001
Location (P>f)		<.0001	0.8481	0.0012	<.0001	<.0001
Treatment x Location (P>f)		0.0002	0.0298	<.0001	0.2506	<.0001

Figure 1. A satellite image of the Lower Shebelle agricultural region illustrating the location of the Afgoi and Awdhegle villages.

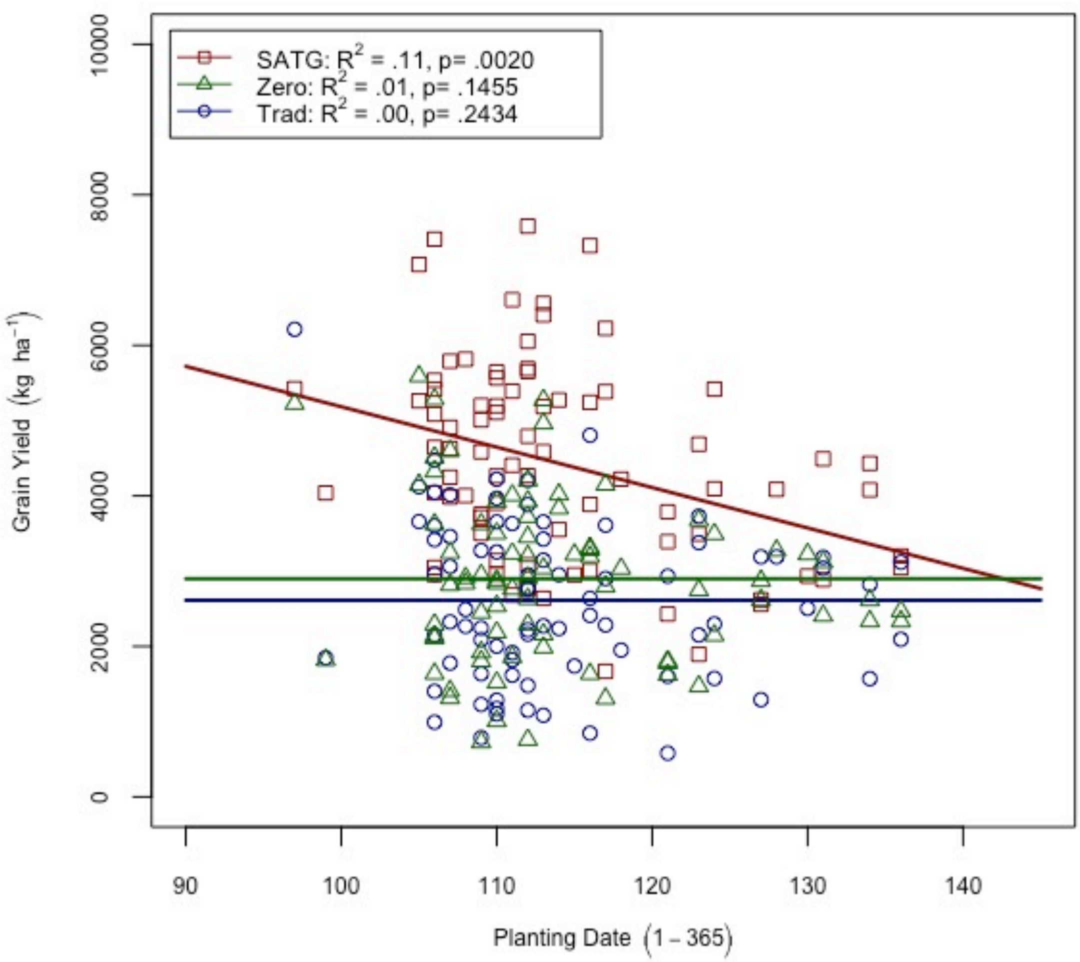

Figure 2. The relationship between grain yield and planting date for different maize production systems in the 2014 Gu season.

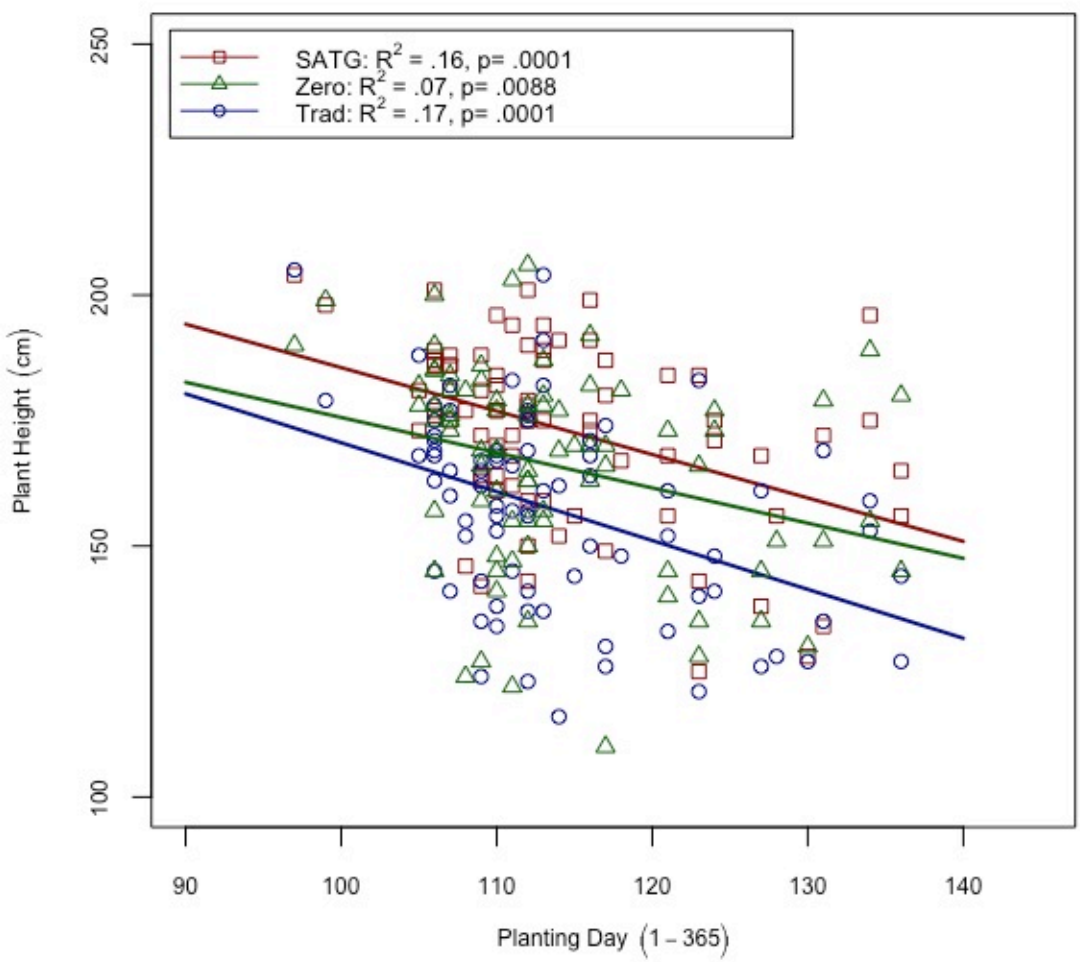

Figure 3. The relationship between plant height and planting date for different maize production systems in the 2014 Gu season.

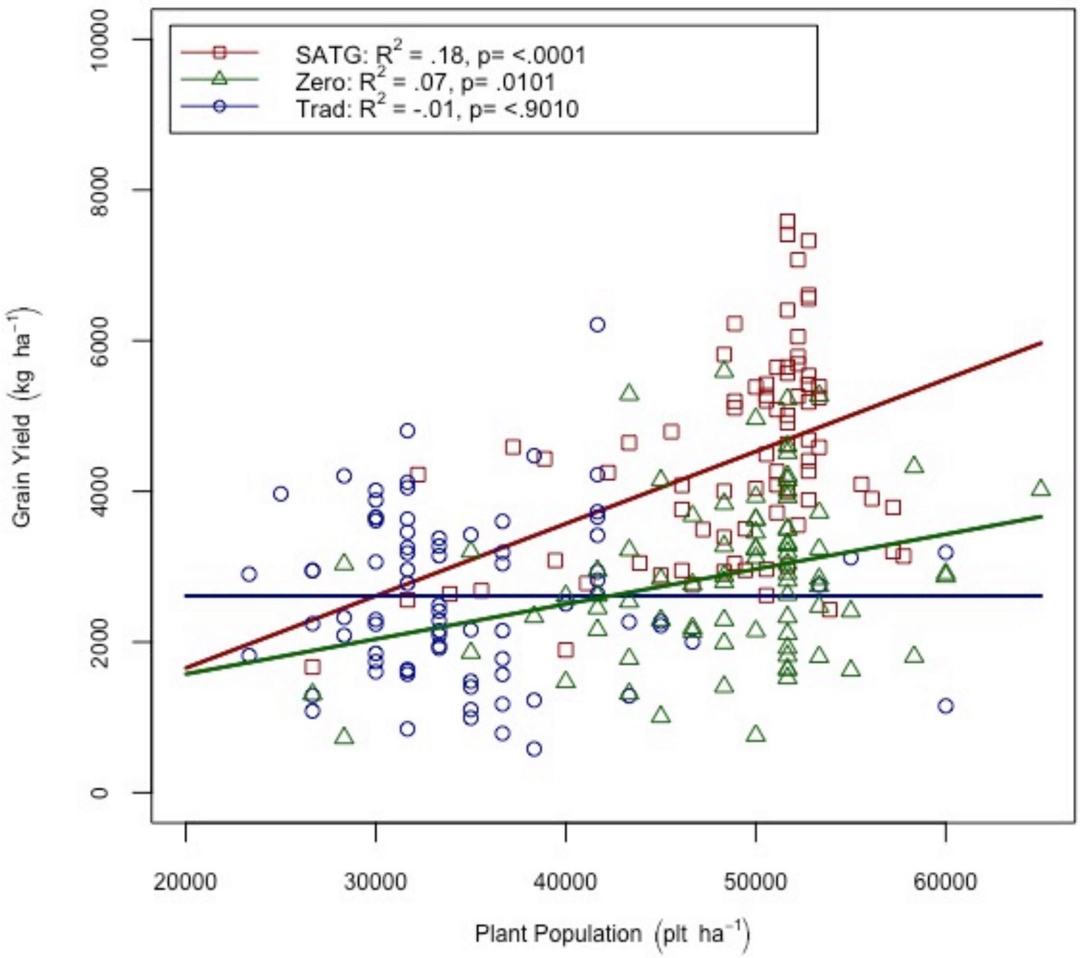

Figure 4. The relationship between grain yield and harvested plant population for different maize production systems in the 2014 Gu season.

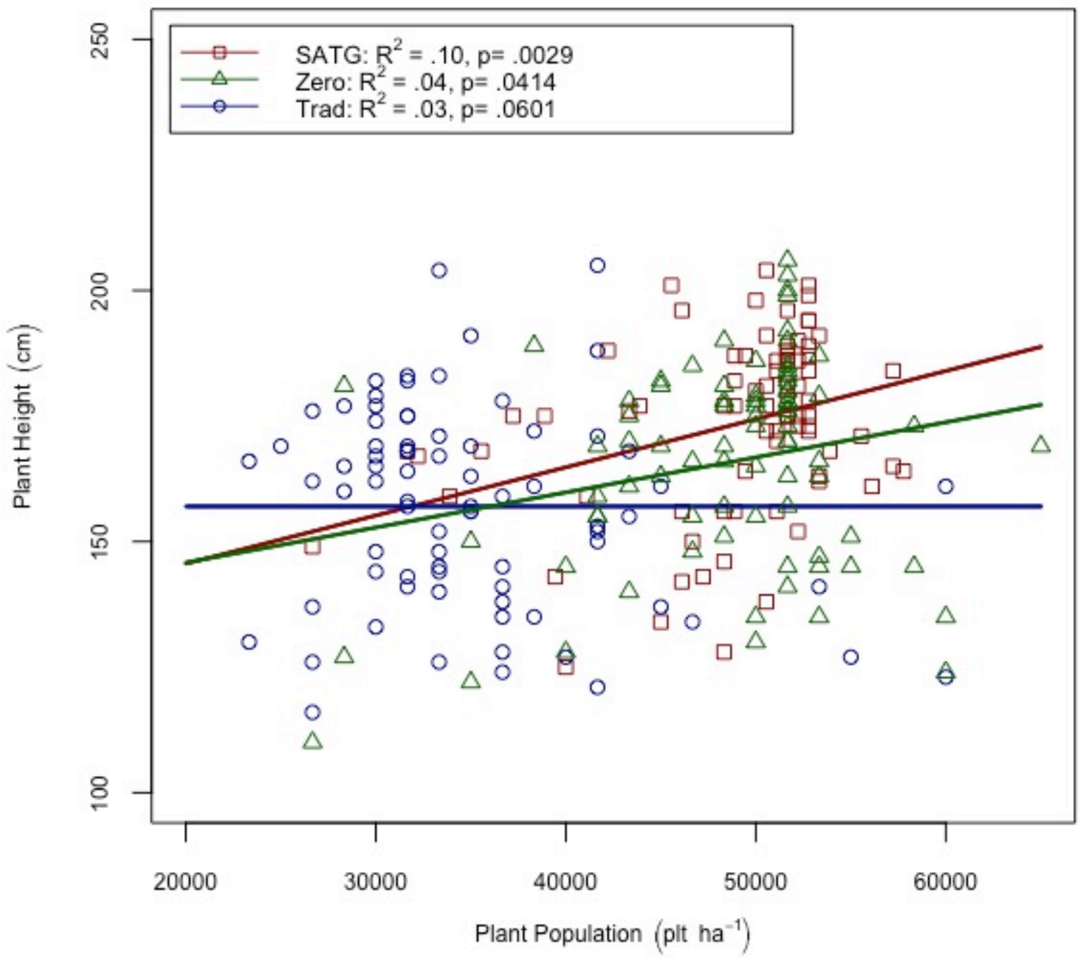

Figure 5. The relationship between plant height and harvested plant population for different maize production systems in the 2014 Gu season.

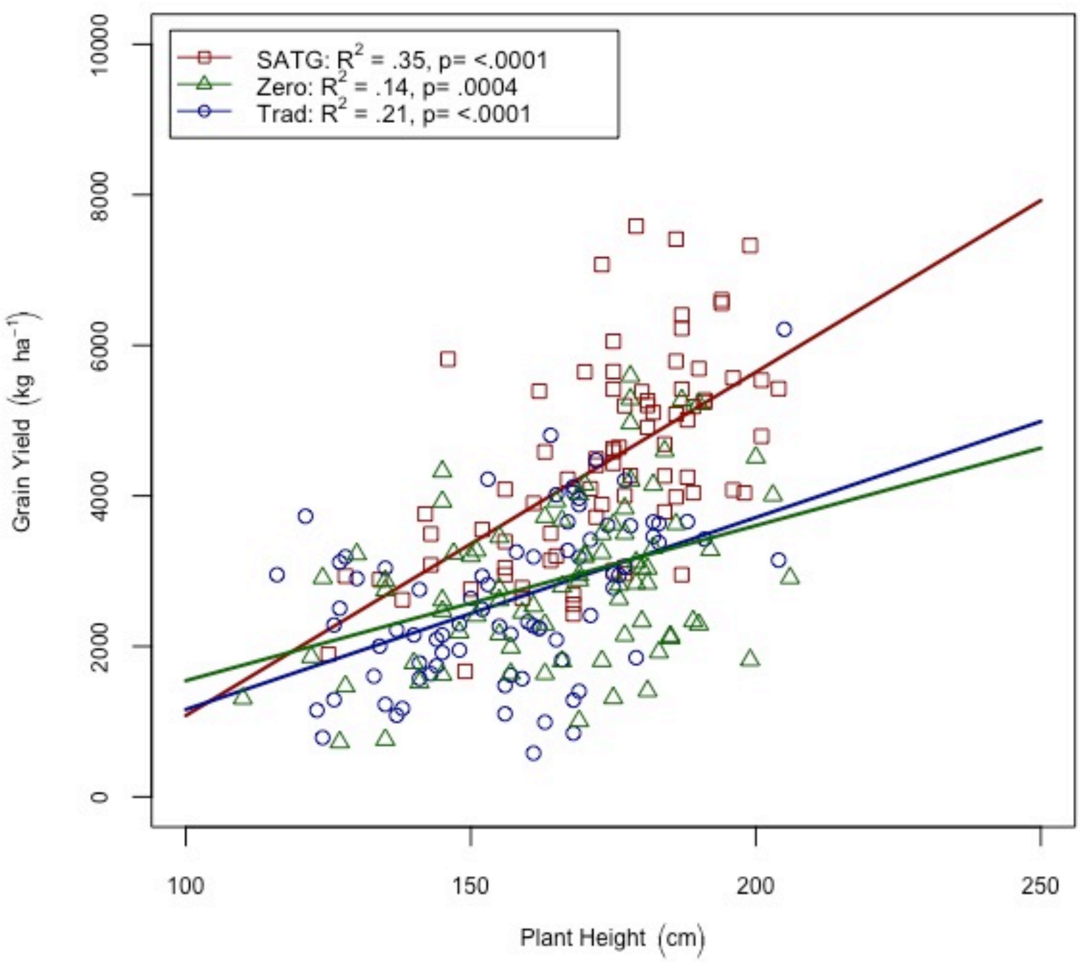

Figure 6. The relationship between grain yield and plant height for different maize production systems in the 2014 Gu season.

Chapter 3

An On-farm Comparison of the Agronomics and Economics of Irrigated Maize Production Systems in the Somali 2014/15 Deyr Season

Summary

Only half of Somalia's cereal requirements are satisfied by domestic production and more than half of the country is considered food insecure. In this study, the Somali Agriculture Technical Group (SATG) used an on-farm participatory research approach to compare the economic viability and plant yield parameters of an improved maize production system with those of the traditional farming system currently employed in the Lower Shebelle region of Somalia. The improved maize production system employed SATG recommended best management practices like the use of mineral nitrogen and phosphorus fertilizers, a pesticide application, and an elevated planting population, while the traditional system did not apply added fertility or pesticides and had a relatively low planting population. This research was conducted on seventy-seven farms located near the cities of either Afgoi or Awdhegle in the 2014/2015 Deyr season, and the results were compared to a separate trial, which was performed on eight-one farms in the 2014 Gu season. When analyzed, significant treatment, seasonal and locational differences emerged. In the 2014/15 Deyr season, the SATG system resulted in a 124% increase in grain yield over that of the traditional system (SATG = 3967 kg ha^{-1}) and had 28% more harvestable plants (SATG = 37254). When compared across seasons, farms employing the SATG system in the 2014 Gu season produced 65% more grain and had 37% more harvestable plants than did farms in the 2014/15 Deyr season (Gu: SATG = 4292 kg ha^{-1}, 48423 plants ha^{-1}). For the traditional system, these numbers were 32% and 18%, respectively (Gu: Traditional = 1771 kg ha^{-1}, 29192 plants ha^{-1}). In both seasons, farms near Awdhegle saw the greatest grain yields. These data indicate that the Gu season is a

more productive maize season, which aligns well with anecdotal evidence from farmers in the region. Locational differences likely resulted from differences in underlying soil properties, like electrical conductivity (EC), and differing irrigation practices between the two areas. Similar trends as those reported above were observed for stover yields, but technical limitations have made these results suspect. When 2014/15 cost and revenue data was analyzed, it was found that growing costs associated with the SATG system were higher (676%) than those of the traditional system, but the SATG system proved to have a higher net revenue (142%) and be more reliably profitable.

Introduction

For more than twenty-five years, the east African nation of Somalia has struggled to overcome the political instability, civil unrest, and infrastructure collapse that occurred when the Siad Barre government fell in 1991. The government failure created a power vacuum, which resulted in a protracted civil war that has left the country relying on an informal economic system struggling with food insecurity (Little, 2008). Today, Somalia is heavily dependent on foreign aid, and the moral imperative to make it as effective as possible necessitates intelligent development strategies. With the majority of its population being rural (WBG, 2016), development schemes that focus on improving rural livelihoods will likely prove most effective in Somalia. One powerful tool for improving these rural livelihoods is agricultural research (Thirtle et al., 2003).

The Somali Agricultural Technical Group (SATG, www.SATG.org) is a nongovernmental organization working to improve rural livelihoods through agricultural research in Somalia's Lower Shebelle region (Figure 1). The current agricultural situation in Somalia is dire. Even with 71% of the country's labor force engaged in agriculture (CIA, 2017) and crop production representing 20% of the country's GDP (Somali Development Bank, 2015), domestic cereal production only satisfies around half of the populations' requirements (FAO, 2012). As a result, Somalia's food security is heavily dependent on imported foodstuffs (Gavin et al., 2018), and it is not uncommon for food to account for 80% of household expenditures (FEWS, 2014).

In 2014 and 2015, as part of the United States Agency for International Development (USAID) funded Partnership for Economic Growth (PEG) project, SATG implemented targeted maize production research in order to improve the economic and food security situation of Somalis. This research investigated the efficacy of a production system, which employed simple best management practices (BMPs) like mineral fertilizers, a chemical pesticide, and an increased planting population, by comparing the maize yield and growth parameters of this system with those of the traditional farming practices utilized in the region. Though they have only begun to be characterized in the Somali context (Gavin et al., 2018), the BMPs employed by the SATG system were selected for their simplicity and because similar practices have been shown to be effective in other geographies. For example, the use of mineral fertilizer in Somalia is rare (Haji, 2017), but it has been recognized as an important tactic for increasing sub-Saharan food production (Mwangi, 1996). Similarly, though plant populations in the Midwestern United States routinely reach 90,000 plants ha^{-1} (Schnabel & Licht, 2017), traditional plant populations in Somalia have been observed to be substantially lower (Gavin et al., 2018; Haji, 2017).

This study took place during the 2014/15 Deyr season and builds on previous work in the 2014 Gu season (Gavin et al., 2018). An on-farm participatory research approach was employed in this trial, with the intention that it would maximize community involvement and lead to durable extension results (Macaulay et al., 1999). This was achieved by utilizing a network of local farmers that had been previously identified by SATG and working closely with them throughout the entire research process. Understandably, the adoption of new agricultural technologies, especially those requiring external inputs, is often hampered by real or perceived economic costs (Muzari et al., 2012). In order to assess the economic impact of the system employing the SATG BMPs, this study also included a simple farm-level economic analysis, which compared the costs and revenues associated with the SATG system to those of the traditional farming system.

Materials and Methods

Maize is one of the principal cereal crops in Somalia, and nearly all maize production takes place on the irrigated and rain-fed farmland along the Shebelle river. The soils of the Lower Shebelle are shaped by alluvial deposits over calcareous, unconsolidated and consolidated sedimentary formations (Jones et al., 2013; Gadain et al., 2016), with Haplic Vertisols (70%), Fluvisols (11%), and Calcisols (2%) dominating the landscape (Jones et al., 2013). With temperatures in the Lower Shebelle only ranging from 27 to 31 degrees Celsius throughout the year, seasonality in the region is driven by rainfall. Rainfall in the Lower Shebelle averages approximately 500 mm annually (Ali, 1988), and maize production takes place during the two wettest seasons. The primary maize growing season is the Gu season, which extends from April through June and has an average rainfall of between 250 and 300 mm (Gavin et al., 2018). The Deyr season is the secondary maize growing season. It has an average rainfall of between 100 and 200 mm and occurs between October and December. Somali farmers must maximize maize yields in each of these seasons in order to ensure an adequate food supply.

During the 2014 Gu and 2014/15 Deyr seasons, SATG utilized a multi-location randomized complete block (RCB) experimental design to evaluate the effects of an improved maize production system, which employed SATG BMPs and will heretofore be referred to as the SATG system, on maize yield and growth parameters. The production characteristics of this improved system were then compared with those of the traditional farming system employed in the region.

This research was performed on the farms of maize producers in the Lower Shebelle region and under the supervision of trained SATG staff. In total, eighty-one farmers participated in the 2014 Gu season trial, and seventy-seven farmers participated in the 2014/15 Deyr season trial, with each of these farmers being associated with an SATG experiment station located near the villages of either Afgoi or Awdhegle. Each participating farmer donated one jibaal (625 m^2) of land to SATG to be managed using the SATG system, while an adjacent jibaal was managed using their own traditional management practices.

The BMPs of the SATG system were relatively simple and contextually appropriate. In both seasons, the SATG system received a pre-plant broadcast application of DAP at a rate of 200 kg ha^{-1} (36 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1}). In the 2014 Gu season, the SATG system received a total urea application rate of 200 kg ha^{-1} (92 kg N ha^{-1}), but this application rate was reduced to 150 kg ha^{-1} urea (69 kg N ha^{-1}) in the 2014/15 Deyr season because separate 2014 Gu season fertility trials performed by SATG indicated diminishing yield returns over 150 kg ha^{-1}. In both seasons, urea was applied via a trench dug alongside each crop row, and the total urea application rate was evenly split into two fertilizing events, one at planting and one at the V3 growth stage.

In the 2014 Gu season, the SATG system recommended a planting population of 53,333 plants ha^{-1}, which was achieved with a plant spacing of 0.75 meters between rows and 0.25 meters within rows. This recommendation was reduced to 44,444 plants ha^{-1} in the 2014/15 Deyr season, because input from participating farmers suggested that increasing the within row plant spacing to 0.30 meters would make weed management by hand hoe less burdensome. No plant population was specified for the traditional treatment, as management decisions for this system were left to each individual farmer.

In both seasons, the SATG system also received an application of the insecticide Bulldock® (Beta-Cyfluthrin), to control for the spotted stem borer, and was subjected to timely weeding and irrigation events. With the exception of land preparation, which is commonly performed with a tractor in the Lower Shebelle, all aspects of field management and harvest for both the SATG and traditional systems were performed by hand. The open-pollinated maize variety "Somtux" was used in both the SATG and traditional farming systems.

Data was collected on each farm by taking the average of two representative 3.0 m^2 subsamples from both the SATG and traditional systems. The main parameters of interest measured in this trial included the grain yield, stover yield, harvested plant population, and harvested cob population of each management system. Grain yield measurements were obtained after the grain had been removed from the cob and sun-dried. After drying, grain moisture measurements were taken with a handheld moisture meter, and grain weights were standardized to a 15.5% moisture content. The stover was also sun-dried before weighing, but because stover moisture content was not assessed, these weights were not standardized to a specific moisture content and must be viewed with skepticism. Further, available technology limited the measurement precision of grain and stover weights to half a kilogram, which likely contributed to the high standard deviations observed in this trial. Harvested plant and cob populations were obtained at the end of the season.

After randomly removing the data from ten farmers, a final balanced dataset, consisting of seventy-four farmers in each season and thirty-seven farmers at each location, was used for the statistical analysis. An analysis of variance (ANOVA) was performed using the package PROC ANOVA in the statistical software SAS™ at a significance level of $\alpha = 0.05$. Mean separation was conducted using Tukey's Honest Significant Difference (Tukey's HSD) post-hoc test (SAS, 2016). Because of this dataset's size, an examination of the relationships that existed between grain yield, planting date, and harvested planting population in the 2014/15 Deyr season was also conducted. These relationships were evaluated via simple regression analyses using the open-source statistical software R (R Core Team, 2016).

A farm-level economic analysis of 2014/15 Deyr season maize production in the Lower Shebelle was also performed. Utilizing data from thirty-one farmers located near Awdhegle, an ANOVA was conducted to better understand how the SATG and traditional systems differed in terms of input costs, gross revenue, and net revenue. This analysis was completed using the PROC ANOVA package in SAS™, with statistical significance assessed at an α level of 0.05 and using Tukey's HSD for post-hoc mean separation (SAS, 2016).

For the economic analysis, input costs were aggregated into six broad cost categories: land preparation costs, planting costs, growing costs, harvesting costs, labor costs, and capital costs. Gross revenues were determined by associating each farmer's maize yield with the average price of maize in the region, 10,000 Somali Shillings (SOS) kg^{-1}. This figure was reported by SATG staff and falls in line with the 2015 average retail maize price, as compiled by the Famine Early Warning System (FEWS) (FEWS, 2015). It should be noted, however, that farm-gate prices may have been lower than retail prices, and in which case, the revenues here reported would be slightly inflated. Currency conversion into USD was conducted using the 2015 U.N operational exchange rate of 1 USD to 24,300 SOS (United Nations, 2017).

Results and Discussion

Data from the 2014 Gu and 2014/15 Deyr seasons mirrored each other closely. The major trends observed in the 2014 Gu season have been previously described by Gavin et al. (Gavin et al., 2018) and will not be exhaustively investigated in this paper. Instead, this paper will focus on the findings of the 2014/15 Deyr season and how they relate to data from the 2014 Gu season (Table 1).

In the 2014/15 Deyr season, a significant management system by location interaction emerged for both the harvested plant and cob population parameters (Table 1). The SATG system had a 28% higher harvested plant population (37254 plants ha^{-1}) than the traditional system and produced 44% more harvestable cobs (36128 cobs ha^{-1}). These differences, however, varied greatly in magnitude, depending on which location was being examined. On farms located near Afgoi, the harvested plant population of the SATG system (35557 plants ha^{-1}) was 16% greater and had 32% more harvestable ears (35870 cobs ha^{-1}) than the traditional system. Near Awdhegle, these numbers were even greater. At 38951 plants ha^{-1}, the harvested plant populations near Awdhegle were 41% and had 58% more cobs (36386 cobs ha^{-1}). These interactions resulted from a combination of relatively high harvested plant populations for the traditional system and lower than expected harvested plant populations for the SATG system on farms located near Afgoi. The harvested plant population of the SATG system was 9% lower in Afgoi (35557 plants ha^{-1}) than in Awdhegle, while the harvested plant population of the traditional system was 11 % higher (30765 plants ha^{-1}).

When the 2014 Gu and 2014/15 Deyr datasets were compared, significant seasonal differences and interactions emerged for both the harvested plant and cob population parameters (Table 1). Higher harvested plant and cob populations were observed in the 2014 Gu season than in the 2014/15 Deyr season, for both the SATG and the traditional systems. The harvested plant population of the SATG system in the 2014 Gu season (48423 plants ha^{-1}) was 30% higher than in the 2014/15 Deyr season and had 32% more harvestable cobs (47635 cobs ha^{-1}). Similarly, the harvested plant population of the traditional treatment in the 2014 Gu season (35428 plants ha^{-1}) was 21% higher than in the 2014/15 Deyr season and had 33% more harvestable cobs (33468 cobs ha^{-1}). Though the harvested plant and cob populations of the SATG system were greater than those of the traditional system in both seasons, these differences were narrower in the 2014/15 Deyr season, which resulted in a significant season by management system interaction. For the SATG system, these seasonal differences in harvested plant and cob population can be explained by SATG's decision to increase their within-row plant spacing recommendation from 0.25 meters in the 2014 Gu season to 0.30 meters in the 2014/15 Deyr season. The seasonal differences observed in harvested plant population for the traditional system. It's possible that, as the Deyr season is the shorter secondary growing season with less rainfall, farmers have learned to reduce their planting populations in order to ensure maximum time and resource efficiency.

Locational differences in harvested plant population were more consistent across seasons, and no significant interaction was observed (Table 1). In both seasons, the harvested plant populations of the SATG system and those of the traditional system were much more closely aligned on farms near Afgoi than on farms near Awdhegle. When the seasonal datasets were combined, the harvested plant population of the SATG system was 18% greater than that of the traditional system on farms near Afgoi (40571 plants ha^{-1}) and 50% greater on those near Awdhegle (45106 plants ha^{-1}). In both seasons, this was caused by relatively high harvested plant populations for the traditional system and lower than expected harvested plant populations for the SATG system on farms near Afgoi. When the seasonal datasets were combined, farms near Awdhegle had an 11% greater harvested plant population for the SATG treatment (45106 plants ha^{-1}) but a 13% lower harvested planting population for the traditional treatment (30093 plants ha^{-1}) than farms near Afgoi. Traditionally, farmers near Afgoi appear to plant more maize than those near Awdhegle. That the harvested plant populations of the SATG system near Afgoi were less than those near Awdhegle can only be explained by improper thinning or planting.

Locational differences in harvested cob population followed similar trends, but a significant seasonal interaction was observed (Table 1). While the difference between the harvested cob populations of the SATG system and those of the traditional system was narrower on farms near Afgoi than on farms near Awdhegle in both seasons, these differences were not uniform across seasons. In the 2014 Gu season, the SATG system had 26% more harvestable cobs than the traditional system at Afgoi (43874 cobs ha^{-1}) and 60% more at Awdhegle (51396 cobs ha^{-1}). In the 2014/15 Deyr season, these numbers were 32% and 58%, respectively (35870 & 36386 cobs ha^{-1}, respectively). This resulted in a significant season by location interaction for harvested cob population, but because harvested cob and plant population are highly related, this interaction can be easily explained by the aforementioned seasonal and locational harvested plant population differences. When the seasonal datasets were combined, farms near Awdhegle had a harvested plant population that was 10% greater for the SATG treatment (43891 cobs ha^{-1}) but 11% lower for the traditional treatment (27519 cobs ha^{-1}).

In the 2014/15 Deyr season, the grain yield of the SATG system (3967 kg ha^{-1}) was 124% greater than that of the traditional system, and this pattern persisted when each location was examined independently. The grain yield of the SATG system was 127% greater than the traditional system on farms near Afgoi (3567 kg ha^{-1}) and 121% greater on farms near Awdhegle (4367 kg ha^{-1}). Farms near Awdhegle exhibited higher grain yields than farms near Afgoi, regardless of which management system was employed. Farms near Awdhegle saw a 22% greater grain yield for the SATG system (4367 kg ha^{-1})

and a 26% greater grain yield for the traditional system (1973 kg ha^{-1}) than farms near Afgoi.

These locational yield disparities can likely be explained by locational differences in soil characteristics and farm management. For the SATG system, where adequate soil fertility has been supplied, these yield differences were most likely caused by the abovementioned locational differences in harvested plant population. For the traditional treatment, however, these locational grain yield disparities were most likely caused by differences in the underlying soil characteristics of the areas. Previous research into the soil properties of the Lower Shebelle saw significant locational differences in soil sand proportion and electrical conductivity (EC) values. Soils near Afgoi had nearly twice as much sand and a tenfold higher EC than those near Awdhegle (Gavin et al., 2018). While the locational differences in sand proportion are unlikely to have majorly influenced plant growth in the heavily clay soils of the Lower Shebelle, the higher EC values observed near Afgoi could have adversely affected crop yields by inhibiting maize seedling development (Maas et al., 1983). Locational differences in irrigation practice could have also influenced grain yields. Farms near Awdhegle are able to use gravity irrigation later in the season than those near Afgoi, who primarily rely on irrigation pumps, and as a result, farmers near Awdhegle may have irrigated more frequently than those near Afgoi (Haji, 2017). Differing irrigation practices could have influenced crop growth and affected soil EC.

When grain yield data was compared across seasons, significant interactions were observed (Table 1). The 2014 Gu season saw higher grain yields than the 2014/15 Deyr season, regardless of management system, but this difference was much greater for the traditional system. While the grain yield of SATG system was 8% higher in the 2014 Gu season (4292 kg ha^{-1}) than in the 2014/15 Deyr season, this difference was 47% for the traditional system (2609 kg ha^{-1}). These differences can probably be best explained by the abovementioned seasonal differences in harvested plant population and slightly harsher growing conditions in the 2014/15 Deyr season. Less rainfall would have affected the ability of farmers to irrigate, and this would have likely had a greater influence on the traditional farming system, because the reduced soil fertility in this system would have inhibited plant growth and limited their ability to scavenge water.

A significant season by location interaction also manifested for grain yield. In both seasons, grain yields were higher on farms near Awdhegle than on farms near Afgoi, but this difference was much greater in the 2014 Gu season than in the 2014/15 Deyr season. Across both cropping systems, farms near Awdhegle saw 45% higher grain yields (4084 kg ha^{-1}) than farms near Afgoi in the 2014 Gu season and 23% higher grain yields in the 2014/15 Deyr season (3170 kg ha^{-1}).

Finally, the effect of production system on grain yield cannot be overstated. When the seasonal datasets were combined, a significant interaction between season and production system was observed, but this interaction was due to differing magnitudes of production system effect in each season and not inconsistencies in production system effects across seasons. When the seasonal datasets were combined, the grain yield of the SATG system (4130 kg ha^{-1}) was 89% greater than that of the traditional treatment, with this difference being 65% in the 2014 Gu season (4292 kg ha^{-1}) and 124% in the 2014/15

Deyr season (3967 kg ha^{-1}). The SATG system may have proved more beneficial in the 2014/15 Deyr season, because in the shorter, less wet Deyr season, the added fertility of the SATG system allowed plants to grow more quickly and scavenge moisture more effectively

While stover yields are here reported, these numbers should be viewed as suspect because of the abovementioned difficulties standardizing stover moisture contents. With this in mind, the stover yield trends observed in these trials can still provide meaningful information about maize production in the Lower Shebelle. In the 2014/15 Deyr season, the stover yield of the SATG system (13452 kg ha^{-1}) was 92% greater than that of the Traditional system. Much of this increase in stover production can be attributed to the significantly higher plant populations recommended by the SATG system. Farms located near Afgoi had more stover than farms located near Awdhegle. When the seasonal datasets were combined, similar trends were observed, with the 2014 Gu season having a higher stover yield than the 2014/15 Deyr season. This seasonal difference could have resulted from seasonal differences in harvested plant population and water availability or moisture content at the time of weighing.

The size and participatory design of the 2014/15 Deyr season trial also made it possible to explore potential grain yield, harvested plant population, and planting date relationships (Figures 2 & 3) via simple linear regression. No statistically significant relationships were observed between grain yield and harvested plant population or grain yield and planting date for the traditional system, but both of these relationships were found to be significant for the SATG system. While the relatively low R-squared of these relationships suggest that they aren't highly explanatory for this trial's data, these data do suggest that when fertility needs are satisfied increasing the plant population and planting early will likely lead to higher grain yields. This was interesting because it suggests that raising plant populations alone will not lead to increased grain production, and that soil fertility is the major constraint in Lower Shebelle maize production systems. It also suggests that the plant populations employed by Somali farmers in their traditional production system are appropriate given their soil fertility limitations. These findings echo and verify those of the 2014 Gu season SATG maize production study (Gavin et al., 2018).

While the abovementioned data have demonstrated that the SATG system improved maize yields in the Lower Shebelle region, the adoption of new agricultural technologies is often hampered by their economic burden (Muzari et al., 2012). So, the SATG system must also prove itself economically viable. When the production cost and revenue data of thirty-one farmers located near Awdhegle in the 2014/15 Deyr season were compared, statistically significant differences were observed between the total revenues, net revenues, capital costs, labor costs, and growing costs of the SATG and traditional systems (Table 2). In each case, the SATG system was found to be costlier but elicit a greater economic return than the traditional system. The land preparation, planting, and harvest costs were not found to be significantly different between the two systems. This is likely because maize farmers in the Lower Shebelle typically rent tractor equipment by the day and rely heavily on family labor at planting and harvest time, regardless of whether the SATG or traditional system was employed (Haji, 2017).

The differences observed between the net revenue and costs of these two systems is of particular importance and relevance to farmers. These data suggest that the perceived economic burden of the SATG system is not unjustified. In the 2014/15 Deyr season, the growing costs of the SATG treatment (540 \$ ha^{-1}) were found to be 671% greater than the traditional system. This cost, however, was more than compensated for by an increase in net revenue. The net revenue of the SATG system (362 \$ ha^{-1}) was 142% greater than that of the Traditional system. Perhaps of more importance was that the SATG system was highly reliable economically. In the 2014/15 Deyr season, the SATG system always resulted in positive net revenues, whereas the traditional system resulted in economic losses for 23% of the participating farmers. The range of net revenues for the SATG system was also 8% narrower than those of the traditional system. With less variability in expected income, farmers can better plan for the future and improve long-term livelihood outcomes via investments in social capital. The increases observed in capital and labor costs can be attributed to expenses like fertilizer and pesticides inputs and extra weeding and irrigation effort, respectively. These economic data further support the argument for wide scale implementation of the SATG system in the Lower Shebelle.

Conclusion

The collapse of the Siad Barre government in 1991 thrust Somalia into a state of political instability and conflict. While many efforts have been made to improve the situation in Somalia, few have focused on performing applied scientific research or building domestic research capacity. This investigation into maize production systems in the Lower Shebelle region of Somalia represents a unique attempt to accomplish both of these development goals. Led by the Somali Agriculture Technical Group (SATG) in the 2014/15 Deyr season, this on-farm research demonstrated that Somali maize farmers can dramatically increase yields and profits by implementing SATG best management practices, with the yield benefits of the SATG system being most effectively captured at higher planting populations and at earlier planting dates. This research also showed that soil fertility is the leading constraint in Lower Shebelle maize production systems and that simply increasing plant populations without adding fertility will not increase maize yields.

These conclusions echo those of maize research performed by SATG in the 2014 Gu season, but that season was found to have significantly higher grain yields, stover yields, harvested plant populations, and harvested cob populations. While far from an exhaustive examination of Somali maize production, this research represents one of the first efforts to perform cropping systems and farm-level economic research in Somalia in more than a quarter century. Future efforts should focus on determining optimal planting densities, soil fertility requirements, and examining different maize germplasm. A more in depth economic analysis is also warranted.

Table 1. Season, location, and production system differences for important maize yield components in the Lower Shebelle.

Treatment	Location	Season	Grain Yield kg ha^{-1}	Stover Yield kg ha^{-1}	Harvested Plant Pop. ha^{-1}	Harvested Cob Pop. ha^{-1}
SATG	Afgoi	Gu	3456	12149	45586	43874
Traditional	Afgoi	Gu	2177	8958	38288	34910
SATG	Awdhegle	Gu	5128	12860	51261	51396
Traditional	Awdhegle	Gu	3040	7928	32568	32027
SATG	Afgoi	Deyr	3567	14581	35557	35870
Traditional	Afgoi	Deyr	1569	7618	30765	27181
SATG	Awdhegle	Deyr	4367	12323	38951	36386
Traditional	Awdhegle	Deyr	1973	6384	27619	23011
SATG	Afgoi	—	3512	13365	40571	39872
Traditional	Afgoi	—	1873	8288	34527	31046
SATG	Awdhegle	—	4747	12592	45106	43891
Traditional	Awdhegle	—	2507	7156	30093	27519
SATG	—	Gu	4292	12504	48423	47635
Traditional	—	Gu	2609	8443	35428	33468
SATG	—	Deyr	3967	13452	37254	36128
Traditional	—	Deyr	1771	7001	29192	25096
—	Afgoi	Gu	2817	10553	41937	39392
—	Awdhegle	Gu	4084	10394	41914	41712
—	Afgoi	Deyr	2568	11099	33161	31526
—	Awdhegle	Deyr	3170	9354	33285	29699
SATG	—	—	4130 a	12978 a	42839 a	41882 a
Traditional	—	—	2190 b	7722 b	32310 b	29282 b
—	Afgoi	—	2692 B	10826 A	37549 A	35459 A
—	Awdhegle	—	3627 A	9874 B	37600 A	35705 A
—	—	Gu	3450 aa	10474 aa	41926 aa	40552 aa
—	—	Deyr	2869 bb	10226 bb	33223 bb	30612 bb

HSD (Treatment)	213	856	1217	1322
HSD (Location)	213	856	1217	1322
HSD (Season)	213	856	1217	1322
R^2	0.71	0.54	0.75	0.77
CV(%)	29.4	36.1	14.1	16.2
Season (P>f)	<.0001	0.57	<.0001	<.0001
Location (P>f)	<.0001	0.0294	0.9344	0.7137
Treatment (P>f)	<.0001	<.0001	<.0001	<.0001
Season x Location (P>f)	0.0023	0.0692	0.9055	0.0023
Location x Treatment (P>f)	0.0058	0.6803	<.0001	<.0001
Season x Treatment (P>f)	0.0184	0.0065	<.0001	0.0204
Season x Location x Treatment (P>f)	0.3397	0.1130	0.0506	0.0342

Table 2. Cost and revenue differences in USD between two maize production systems in the 2014/15 Somali Deyr season.

	Total Revenue $ ha-1		Net Revenue $ ha -1		Capital Cost $ ha-1		Labor Cost $ ha -1		Preparation Cost $ ha-1	Planting Cost $ ha -1	Growing Cost $ ha-1		Harvest Cost $ ha -1
SATG	1277	A	362	A	390	A	525	A	178	85	540	A	112
Traditional	592	B	149	B	186	B	256	B	178	82	70	B	112
HSD	77		82		4		16		NS	NS	17		NS
R^2	0.84		0.31		0.99		0.95		NS	NS	0.98		NS
CV(%)	16.3		63.2		2.7		8.1		NS	NS	10.7		NS
Treatment (P>f)	<.0001		<.0001		<.0001		<.0001		NS	NS	<.0001		NS

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

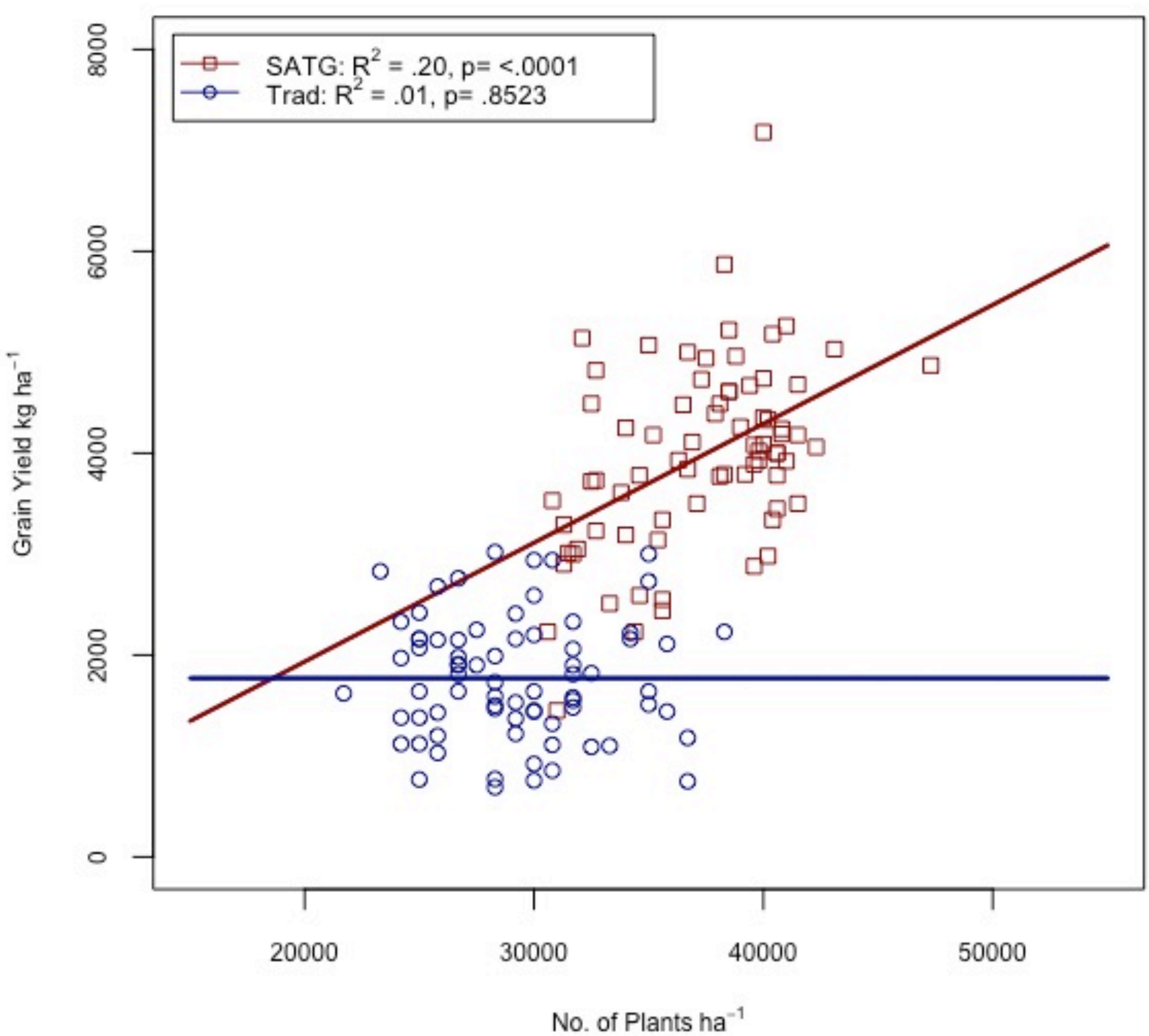

Figure 2. A simple regression examining the relationship between grain yield and the number of plants harvested.

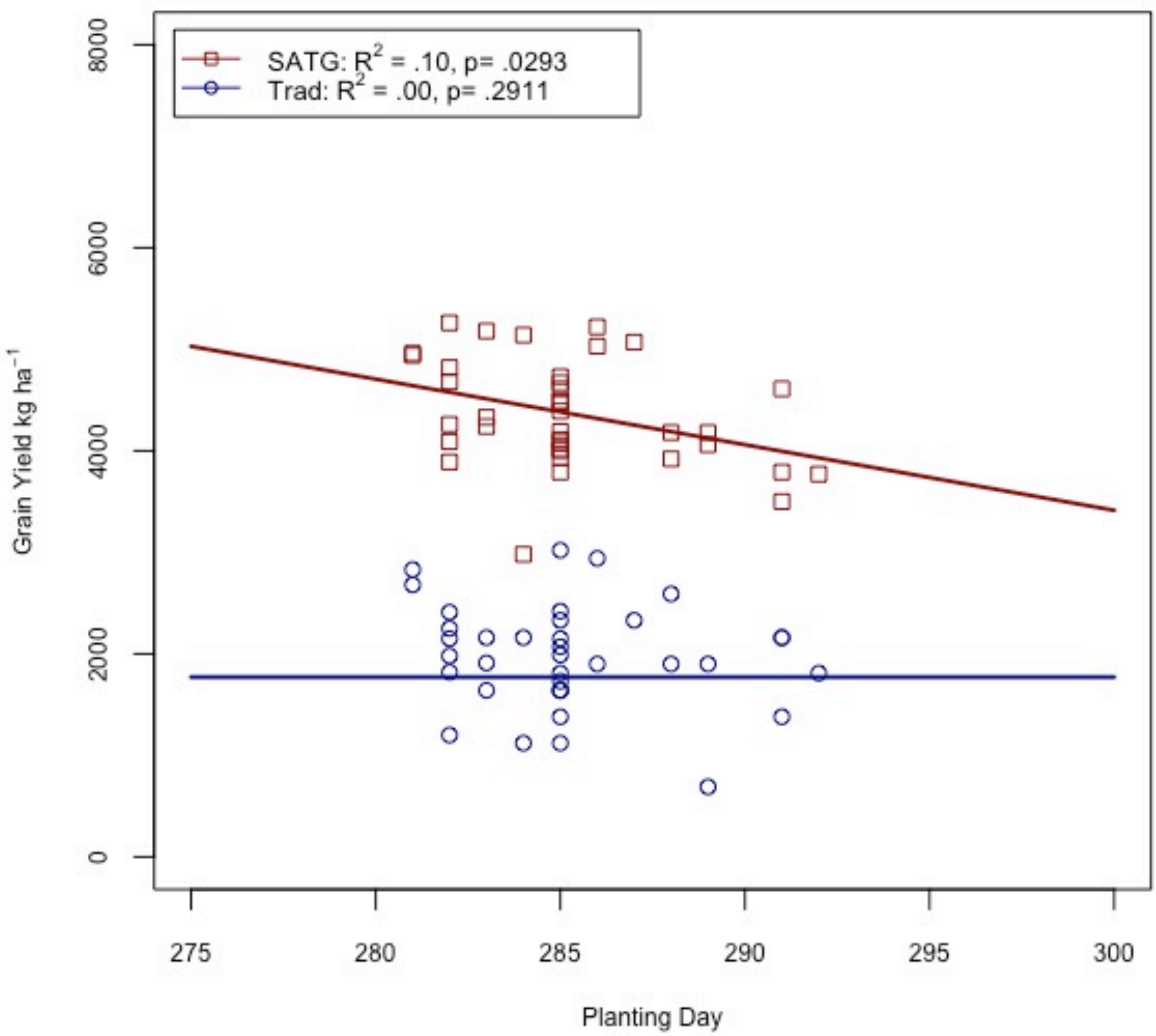

Figure 3. A simple regression examining the effect of planting date on grain yield.

Chapter 4

Varietal and Agronomic Characteristics of Sesame Production in the Lower Shebelle Riverine of Somalia

Summary

Sesame is a promising income-generating crop being grown for export in Somalia, but as yet, little has been done to understand or improve sesame production systems in the Somali environment. This paper describes a series of five trials conducted by the Somali Agriculture Technical Group (SATG) in the Lower Shebelle region of Somalia during the 2016 Hagai and 2016/17 Deyr season. Seven different varieties were examined in two separate trials and the effects that planting date, planting population, and mineral nitrogen fertilizer had on the Local and Humera varieties were explored in three trials. In both varietal trials, grain yield and different morphological traits varied significantly with variety. The Local (506-917 kg ha^{-1}) and Yemeni (597-937 kg ha^{-1}) varieties were amongst the best yielding varieties in both trials. In each of the agronomic trials, the Local (396-571 kg ha^{-1}) produced more sesame seed than the Humera (253-466 kg ha^{-1}), but none of the experimental factors (date of planting, planting population, or mineral nitrogen addition) elicited meaningful grain yield effects. It should be noted, however, that these trials were fraught with plant survival problems, as evidenced by harvested plant populations that were significantly below desired levels, which could have affected data interpretation. Variety appears to be the driving force behind sesame yields in the Lower Shebelle region, and Somali sesame production can be significantly improved by increasing the penetration of Local and Yemeni on the landscape. Future research should focus on improving the food processing acceptability of these varieties and determining their optimal planting density.

Introduction

Since the collapse of the Siad Barre regime in 1991, Somalia has been politically unstable and relied heavily on an informal economy (Little, 2008). As a result, 73% of its population now live on less than two dollars a day (WFP, 2015), and multiple stakeholders have been left searching for new development opportunities. One of these opportunities lies in agricultural research. Investing in agricultural research has already been shown to be highly productive in developing countries (Alston et al., 2000), and as 60% of the Somali population is rural (WBG, 2016) and crop agriculture represents 20% of the Somali economy (Somali Development Bank, 2015), this strategy could yield high social and economic returns in Somalia.

One potential candidate for this investment is the annual oilseed sesame (*Sesamum indicum*). First domesticated on the Indian subcontinent (Bedigian, 2003), sesame is native to Africa and is one of the world's most important sources of vegetable oil (Zerihun, 2012). It is also an incredibly resilient crop that can be effectively grown on marginal land (Ashri, 1998) without the use of expensive external inputs (Taylor & Chambi, 1986). This makes sesame a favorite cash crop for smallholder farmers (Taylor & Chambi, 1986), with the majority of sesame production taking place in developing countries (Mahmoud, 2012).

Though world sesame production continues to rise, and neighboring Ethiopia is among the world's top producers, total sesame production in Somalia hasn't improved in over two decades (FAO, 2017). Between 2012 and 2013, however, Somali sesame seed exports jumped 387%, from 7,478 to 36,419 t, (FAO, 2017), indicating that Somali sesame is well accepted in the global marketplace. Increasing Somali sesame production, therefore, represents a promising income-generating opportunity for smallholder farmers in Somalia. To date, however, nearly no agronomic research exists on Somali sesame production. The Somali Agricultural Technical Group (SATG, www.SATG.org), a Somali-based nongovernmental agricultural research organization, is working to address these research deficiencies. In this paper, the findings of five different trials, in which SATG evaluated the yield components of various sesame varieties and explored possible agronomic best management practices, are presented. This research was funded by the Department for International Development (DFID) under the Promoting Inclusive Markets in Somalia (PIMS) initiative.

Materials and Methods

In southern Somalia, seasonality is dictated by rainfall and temperature. During the 2016 Hagai season, which extends from July through September, and the 2016/2017 Deyr season, which extends from October through January, SATG conducted five studies on the varietal and agronomic characteristics of sesame production in the Lower Shebelle region of Somalia. These studies took place at the SATG regional experiment stations near Afgoi and Balad and were conducted under the supervision of trained SATG extension agents (Figure 1).

The experimental design, factors of interest, season, location, variety, desired plant population, fertility, planting date, harvest date, plants hill^{-1}, plant spacing, plot size, harvest area, and previous crop of each trial are detailed in Table 1, but in each trial, sesame management followed the same basic procedure. Before planting, the sesame fields were flood-irrigated for three successive days. This is a common practice amongst sesame producers in the region and serves to both increase soil moisture and suppress weeds. After flooding, the fields were allowed to dry for three to four days before land preparation was performed by tractor. Land preparation included an initial ploughing of the field, followed by harrowing, farrowing, and ridging. During this preparation, 150 kg ha^{-1} of diammonium phosphate (DAP) (27 kg N ha^{-1}, 69 kg P_2O_5 ha^{-1}) was applied to ensure the adequate soil fertility. Soils in the region have been characterized as heavy in clay with a high CEC and pH above 8.0 (Gavin et al., 2018) .

The sesame was then planted via the "water bottle method." In this method, five holes are drilled into the top of a plastic water bottle and the bottle is filled with sesame seeds; shaking the water bottle releases approximately 5 to 7 sesame seeds at a time. This method was used to distribute seeds in small clusters, or hills, along the top of the ridges. The seeds were then covered and allowed to germinate before being thinned to the desired number of plants $hill^{-1}$, as specified by each experimental design. It should be noted that the harvested plant populations were substantially lower than desired for each trial presented in this paper.

Beyond the initial pre-plant flooding, no further irrigation events occurred in any of these trials. Each trial also received three to four weeding events that coincided with an application of neem oil, a natural pesticide used to control sesame webworm, *Antigastra catalaunalis*. All plot management was performed by hand, and the neem oil was prepared by mixing one milliliter of oil with one liter of water. Seed yield, stover yield, and seed capsule^{-1} data were collected at harvest, while plant height, capsule height, degree of branching, number of capsules plant^{-1}, capsule length, and harvested plant population data were collected prior to harvest. In Trial 2, nitrogen was applied in the form of urea.

Data from these trials were analyzed via an analysis of variance (ANOVA) at a significance level of $\alpha = 0.05$. This was performed using the PROC ANOVA package in the statistical software SAS, and the post-hoc Fisher's Least Significant Difference (LSD) test was used for mean separation (SAS, 2016).

Results

Sesame research in the 2016 Hagai season and 2016/2017 Deyr season followed two major research themes. The first of these themes was to test the efficacy of new varieties in southern Somalia. To achieve this, a variety trial was performed near Balad during the Hagai season (Trial 1) and near both Afgoi and Balad during the Deyr season (Trial 5). In total, the plant yield and growth characteristics of seven different sesame varieties were assessed, with six varieties tested in each trial. The second major theme of this research was to investigate the production agronomics of the Local and Humera varieties; the varieties that currently dominate the Somali sesame landscape. To achieve this, agronomic trials were performed near Afgoi during both the Hagai and Deyr seasons (Trials 2,3,4).

Trial 1. Sesame yield and yield parameters of six varieties grown at Balad in 2016 Hagai.

Trial 1 was a variety trial that took place on the Balad experiment station during the 2016 Hagai season. Six sesame varieties were planted on 0.65 m rows for a desired plant population of 231,000 plants ha^{-1}, though final plant stand data was not recorded (Table 1). In order to simplify data collection and increase varietal seed stocks, the harvested area for Trial 1 was greater than that of the other trials discussed in this paper (Table 1.). The seed yields observed among the six tested sesame varieties varied widely, with a range of 463 kg ha^{-1} (474 to 937 kg ha^{-1}). At 917 kg ha^{-1}, the seed yield of the Local variety was among the highest observed. Though not significantly different from the Yemeni and Setit varieties, it was significantly greater than that of the Nigerian, Humera, and Abasena varieties, out-yielding them by 36%, 45%, and 48%, respectively (Table 2.).

Similarly, with stover yields ranging from 2250 to 3910 kg ha^{-1}, the Local variety was a top producing stover varieties tested (Table 2). The stover yield of the Local variety (3911 kg ha^{-1}) did not differ significantly from those of the Setit, Yemeni, and Abasena varieties, but it was 33% greater than that of the Humera and 42% greater than that of the Nigerian. The Local variety saw the greatest degree of branching (7 branches $plant^{-1}$), with 40% more branches than that of the least branched variety, Nigerian. A range of 26 cm was observed between the seed capsule heights of the six varieties, with the Local and Yemeni varieties having the tallest first seed capsules. The capsule height of the Local variety (61.6 cm) was 42% greater than that of the Nigerian, which demonstrated the shortest seed capsule height in the trial. The number of seeds capsule^{-1} also varied significantly with variety. At 68, the Abasena and Nigerian varieties had the greatest number of seeds capsule^{-1}. This was 15% more than the number of seeds capsule^{-1} observed for the Local variety. No significant differences in plant height or capsules plant^{-1} were observed amongst the six varieties.

Trial 2. Effect of nitrogen fertility, population, and variety on sesame yield and yield parameters at Afgoi in 2016 Hagai.

Trial 2 was performed at the Afgoi experiment station during the 2016 Hagai season. It examined the influence of three fertility rates and two plant densities on the Local and Humera sesame varieties (Table 1.). Plant spacing was maintained at 0.65 m row widths and a between-hill spacing of 0.20 m, with either 2 or 4 plants hill^{-1}. This resulted in desired plant populations of either 154,000 or 308,000 plants ha^{-1}. Actual plant populations at harvest were substantially less than those desired, averaging 125,000 and 185,000 plants ha^{-1}, for the 2 and 4 plants hill^{-1} treatments, respectively. The extreme gulf between the desired and harvested plant populations for the 4 plants hill^{-1} treatment likely resulted from poor plant survival and an improper understanding of a complicated experimental design.

Even so, the harvested plant populations observed for the two and four plants hill^{-1} treatments were significantly different, and plants in the lower harvested plant population group exhibited a higher degree of branching and a greater number of capsules plant^{-1} (Table 3). Besides these differences, however, no other significant plant population or population by variety interactions were observed in either regression (data not shown) or ANOVA analyses (Table 3). Similarly, the different nitrogen fertility treatments did not significantly influence any parameter of interest in this trial. Seed yield (571 kg ha^{-1}) and stover yield (3162 kg ha^{-1}) of the Local variety were 126% and 35% greater, respectively, than those of the Humera variety. Local variety plants were also significantly taller (105.7 cm), exhibited a significantly greater degree of branching (5.2 branches $plant^{-1}$), and had significantly more seed capsules $plant^{-1}$ (71.6 capsules $plant^{-1}$) than the Humera variety.

Trial 3. Effect of planting population on yield and yield parameters of two sesame varieties at Afgoi in 2016/17 Deyr.

Trial 3 took place at the Afgoi experiment station in the 2016/2017 Deyr season (Table 1.) and was designed to evaluate the influence that plant population, as determined by row spacing, had on yield components of the Local and Humera varieties (Table 4.). In this trial, the between-row spacing ranged from 0.4 m to 0.6 m, while a within-row spacing of 0.2 m between hills and 2 plants $hill^{-1}$ was maintained for each treatment. This resulted in a desired plant population of 250,000, 200,000, and 167,000 plants $hectare^{-1}$ for the 0.4 m, 0.5 m, and 0.6 m row spacing treatments, respectively. However, like in Trial 2, there were major disparities between desired and harvested plant populations, with the observed plant population being 190,000, 185,000, and 116,000 plants $hectare^{-1}$ for the .4 m, .5 m, and .6 m row spacing treatments, respectively. These differences can likely be attributed to poor plant survival and improper thinning.

In this trial, harvested population by variety interactions were observed for the seed yield and capsule height parameters (Table 4). For the Local variety, seed yield and capsule height tended to decrease as plant row spacing increased, whereas for the Humera variety, the 0.5 m plant row spacing demonstrated the greatest yield. While initially confusing, this interaction is explained when the number of plants actually harvested is taken into account. For the Local variety, as expected, plant population at harvest increased as row spacing decreased. In the case of the Humera variety, however, the 0.5 m row spacing saw the greatest plant population at harvest, followed by the 0.4 m and the 0.6 m. So, while treatment interactions were observed, in the case of both seed yield and capsule height, both varieties followed the same pattern. The stover yield of the Local variety (1598 kg ha^{-1}) was 84% greater than that of the Humera variety. Row spacing did not significantly effect on stover yield.

Unsurprisingly, final harvested plant populations were affected by row spacing, however, as mentioned above, these differences did not necessarily follow the pattern anticipated by the experimental design (Table 4). For the Local variety, harvested plant population increased as row spacing decreased, but the was not the case for the Humera variety, which had the greatest harvested plant population at the 0.5 m row spacing. Interestingly, this did not result in a harvested plant population by variety interaction, and across both varieties, the 0.6 m row spacing resulted in significantly lower harvested plants than the 0.4 m and 0.5 m row spacing, which did not differ from each other.

Plant heights varied significantly with both variety and row spacing. The height of the Local variety (93 cm) was 17 % taller than the Humera, with the tallest plants being observed at the narrowest row spacing. Similarly, capsule heights varied significantly with variety, with the capsule height of the Local variety (59 cm) being 42% greater than that of the Humera variety. Unlike plant height, however, row spacing did not affect capsule height or plant branching, with longer capsules exhibited by the Humera variety (2.9 cm) and greater branching by the Local variety (3.8 branches plant^{-1}). The number of capsules plant^{-1} did not vary significantly with variety or row spacing.

Trial 4. Effect of planting date on yield and growth of two sesame varieties at Afgoi in 2016/17 Deyr.

Trial 4 took place at the Afgoi experiment station during the 2016/207 Deyr season and examined the influence that planting date had on yield components of the Humera and Local sesame varieties (Table 1.). The sesame was planted at a rate of two plants hill^{-1} on 0.4 m rows with 0.2 m between hills for a desired plant population of 250,000 plants ha^{-1}. As in the abovementioned trials, this trial's plant population at harvest was substantially less than desired, averaging only 205,700 plants ha^{-1}, though no significant difference between the Humera and Local varieties was observed (Table 5).

Unlike previous trials, which suggested strong varietal differences in seed yield, seed yield was not affected by either variety or planting date in this trial (Table 5.). Stover yields were not significantly affected by variety, but earlier planting was associated with significantly greater stover yield, with a decrease of 26% being observed between the earliest (1683 kg ha^{-1}) and latest planting date. Though plant heights in the abovementioned trials varied significantly between the Humera and Local varieties, variety did not influence plant height in this trial. Early planting dates, however, were associated with significantly taller sesame plants, with a difference of 14% being observed between the earliest (100.4 cm) and latest planting date. Unlike plant height, seed capsule height varied significantly by variety but was unaffected by planting date, with the Local variety exhibiting greater seed capsule heights (57.3 cm). A higher degree of branching was observed with earlier planted sesame, regardless of variety, but as in the abovementioned trials, the Local variety plants were more highly branched (4.5 branches plant^{-1}). Neither seed capsule length or the number of seed capsules plant^{-1} were significantly affected by variety or planting date.

Trial 5. Sesame yield and yield parameters of six varieties grown at Afgoi and Balad in 2016/17 Deyr.

Trial 5 took place at the Afgoi and Balad experiment stations during the 2016/2017 Deyr season and was designed to evaluate the yield components of six different sesame varieties at two locations. In this trial, the sesame crop was planted on .4 m row widths with a within row spacing of 0.2 m and 2 plants hill^{-1}, for a desired plant population of 250,000 plants ha^{-1} (Table 1). However, it should be noted that the actual plant populations at harvest were below this desired level, especially at Balad (Table 6.). While in the previous trials much of the difference between desired and harvested plant populations can be explained by poor plant survival rates in a harsh environment, the locational differences observed in this trial were likely caused by improper plant thinning at Balad. While this locational difference was significant, no significant interaction between variety and location was observed for any of the trial's parameters of interest, so the trial was analyzed as designed rather than broken into separate location-specific variety trials.

Surprisingly, no significant difference in seed yield emerged between the Afgoi and Balad locations (Table 6). This is interesting given the significantly different harvested plant populations at each location, and suggests that variety was a much more important yield determinate than plant population in the Lower Shebelle. The Local, Indian-G, and Yemeni varieties produced the greatest amount of seed and were not significantly different from each other. With a seed yield of 506 kg ha^{-1} across both locations, the Local variety exhibited a 44% greater seed yield than the lowest yielding variety, Setit.

The degree of branching and the height of seed capsules were significantly affected by variety and location, with the Local variety having the highest first capsule (78.8 cm) and exhibiting the greatest degree of branching (5.3 branches $plant^{-1}$). Plants at Afgoi were 20% less branched (4 branches $plant^{-1}$) but had 89% higher first capsules (85 cm) than plants at Balad. These locational differences are unsurprising given that the harvested plant population at each location was so different and plant proximity has been shown to significantly affect sesame capsule height directly and plant branching inversely (Delgado, 1975). Likely a result of these locational differences in branching, sesame plants at Balad were found to have significantly more capsules $plant^{-1}$. Neither variety nor location demonstrated a significant effect on the stover yield or plant height.

Discussion

Because this paper encompasses so many different trials, it makes the most sense to discuss their results in aggregate. These results can be categorized as variety, planting population, nitrogen fertility, or planting date related.

Varietal Influences

In both variety trials (Trials 1 & 5; Tables 2 &6), variety proved to be a significant determinate of sesame seed yield, with the Local variety emerging as one of the top yielding varieties. Significant varietal differences in stover yield only manifested in Trial 1, but in each trial, the Local variety had among the highest stover yield, the tallest plants, the tallest first capsule height, and exhibited the greatest degree of branching. Though planting population and proximity are also explanatory for some of the observed differences in these yield components (Delgado & Yermanos, 1975), these data suggest that the Local variety is well adapted to the Somali environment. This finding is not completely unsurprising given that the Local variety has been cultivated in the Lower Shebelle for generations. Further varietal research should focus on other important consumer and processing traits like seed color and oil quality (Ashri, 1998; Haji, 2017) and improving the Local variety through concerted breeding efforts.

Planting Population Differences

Two trials (Trial 2 & 3; Tables 3 & 4) incorporating plant population as an experimental factor were conducted, with each trial examining the effects of plant population on the yield components of the Local and Humera sesame varieties. Plant branching was found to have a significant inverse relationship with population as mediated by the number of plants hill^{-1} in Trial 2 but no relationship when mediated by row spacing in Trial 3. The results of Trial 2 are likely more typical, as past research suggests that increased plant proximity reduces sesame plant branching (Delgado & Yermanos, 1965). The number of capsules plant^{-1} was directly related to the number of plants hill^{-1} for the Humera variety and inversely related for the Local variety in Trial 2. The response of the Local variety was more in line with expectations given that increased plant branching results in greater capsules plant^{-1} and plant branching decreases as plant proximity increases (Delgado & Yermanos, 1975). The response of the Humera variety was, therefore, either atypical, a variety-specific adaptation, or the result of poor data collection. No relationship between capsules plant^{-1} and row spacing mediated population was observed in Trial 3. Seed yield had a significant direct relationship with plant population in Trial 3. While a significant variety by population interaction did manifest, this interaction can be explained by examining the data for the number of plants actually harvested. For the local variety, the number of plants harvested had a consistent inverse relationship with row spacing, as expected, but for the Humera variety the number of plants harvested was greatest at an intermediate row spacing, which also saw the highest Humera variety seed yield. This means that while an interaction between population and variety was observed, the overall trend was consistent across varieties; the greatest seed yields were observed at the highest harvested plant populations. No relationship between plants hill^{-1} mediated population and seed yield was observed in

Trial 2. Regression analyses were performed on these data to better understand the relationship between seed yield and plant population in the Lower Shebelle (data not shown), however, no significant relationships were observed. As neither of these trials were designed to determine optimal sesame planting population, future investigations should focus on developing a proper planting population curve for sesame production in the Lower Shebelle.

Nitrogen Fertility Differences

The effects of additional nitrogen fertility on the yield components of the Local and Humera varieties in the Lower Shebelle were assessed in Trial 2 (Table 3.), but no significant effects on any of the trial's yield components manifested. Nitrogen, therefore, does not appear to be a major constraint for sesame production in the Lower Shebelle. This is in keeping with previous descriptions of sesame as resilient and not reliant on external inputs. (Ashri, 1998; Taylor & Chambi, 1986).

Planting Date Differences

In Trial 4 (Table 5.), planting date was found to have a significant influence on the yield components of the Local and Humera varieties in the Lower Shebelle. Significant effects on plant branching, plant height, and sesame stover yield were observed, but no effect on sesame seed yield was observed. Overall, later planting appears to produce shorter, less branched sesame plants and thus reduces sesame stover production. This aligns well with a previous study, which found that planting date influenced sesame plant development (Mulkey et al., 1987), but some differences between this study and Trial 4, particularly in respect to the effect of planting date on seed yield, suggest that further research effort should be dedicating to determining an optimal planting date range in the Lower Shebelle. This should be done for both the Deyr season, which was examined in Trial 4, and the Hagai season, which has not yet been explored.

Conclusion

Somalia has been plagued by conflict since the fall of the Siad Barre government in 1991. As a result, the country's economy has stagnated and the Somali population has suffered greatly. Somali sesame production represents one possible solution. Sesame is a burgeoning income-generating crop in Somalia, but little formal investigation into Somali sesame production has been performed. The trials outlined in this paper were undertaken by SATG in order to address these research gaps. Based on these trials, variety appears to be the major determinate of yield in Somali sesame production systems, and the Local variety, with yields ranging from 396 to 917 kg ha^{-1} across the five trials conducted, was consistently among the highest yielding varieties tested. Neither planting population nor nitrogen fertility appear to majorly affect sesame yield components in Lower Shebelle production systems. Planting date, however, did have an effect on sesame plant development and early planting should be recommended. Though more targeted and robust investigation into the agronomics of Somali sesame is warranted, these trials represent a first step towards developing an export-oriented Somali sesame industry that could generate sustainable incomes for Somali farmers.

Table 1. Experimental parameters in the sesame research trials conducted in the Lower Shebelle region of Somalia during the 2016 Hagai and 2016/17 Deyr seasons.

Trial	Factors of Interest	Season	Location	Experimental Design	Variety, Planting Date, Harvest Date, and Plant Population[1]
1	Variety	Hagai	Balad	RCB with 4 Rep and 6 Var	Humera, Abasena, Setit, Yemeni, Local, and Nigerian; planted 7/10/016; harvested 10/3/2016; plant population 231,000 plants ha^{-1}
2	Variety, Fertility and Plant population	Hagai	Afgoi	RCB with 3 Rep in a split-plot factorial (2 Var and 3 Fert) as main plots and 2 Den as the split plot	Humera and Local; planted 6/20/2016; harvested 9/25/2016; fertility: 0, 15 & 30 kg Urea ha^{-1}; plant population 154,000and 308, plants ha^{-1}
3	Variety and Plant population	Deyr	Afgoi	RCB with 3 Rep arranged in a two-way factorial (2 Var and 3 Den)	Humera and Local; planted 10/22/2016; harvested 1/17/2017; plant population 167,000, 200,000, and 250,000 plants ha^{-1}
4	Variety and Date of planting	Deyr	Afgoi	RCB with 4 Rep arranged in a two-way factorial (2 Var and 3 Date)	Humera and Local; planted 10/22/16, 10/29/16, and 11/5/16; harvested 1/17/17, 1/21/17, and 1/31/17; plant population 250,000 plants ha^{-1}
5	Variety And Location	Deyr	Afgoi & Balad	RCB with 4 Rep at 2 Loc and 6 Var	Humera, Indian-G, Setit, Yemeni, Local, and Nigerian; planted 10/22/16 (Afgoi), 11/14/16 (Balad); harvested 1/29/2017 (Balad), 1/15/2017 (Afgoi); plant population 250,000 plants ha^{-1}

Table 1, continued.

Trial	[1]Plant Population: Row width (rw), spacing between hills (sbh) and plants $hill^{-1}$ (pph)	Plot Size	Harvest Area	Previous Crop
1	0.65m rw, 0.20m sbh, and 3 pph	34.2 m2	34.2 m2	Maize
2	0.65m rw, 0.2m sbh, and 2 pph	23.4 m2	2.6 m2	Mixed Vegetables
3	0.40, 0.50 & 0.60m rw, 0.20m sbh, and 2 pph	40.0 m2	2.4 m2	*Legumes
4	0.40m rw, 0.20m sbh, and 2 pph	40.0 m2	2.4 m2	*Legumes
5	0.40m rw, 0.2m sbh, and 2 pph	40.0 m2	2.4 m2	Maize (Balad), *Legumes (Afgoi)

Table 2. Sesame yield parameters of six varieties grown at Balad in the 2016 Hagai season (Trial 1).

Variety	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Plant height cm	Capsule height cm	Branches plant^{-1}	Seeds capsule^{-1}	Capsules plant^{-1}
Humera	503 B	2610 BC	97.6	37.9 C	4.4 C	62.5 AB	59.0
Abasena	474 B	2000 ABC	107.5	50.6 B	5.6 B	68.0 A	46.5
Setit	740 AB	3210 ABC	106.5	38.9 C	4.3 C	63.3 AB	68.6
Nigerian	583 B	2250 C	92.9	35.6 C	4.2 C	68.0 A	84.7
Local	917 A	3910 A	121.2	61.6 A	7.0 A	59.1 B	76.3
Yemeni	937 A	3480 AB	106.7	55.1 AB	5.4 BC	59.2 B	51.0
LSD	326	1066	NS	8.91	1.21	7.0	NS
R^2	0.59	0.57	0.46	0.84	0.74	0.56	0.53
CV (%)	31.3	23.1	12.6	1278	15.6	7.34	33.4
P>f	0.0255	0.0508	0.1138	<.0001	0.0010	0.0463	0.1521

Table 3. Effect of fertility, population, and variety on sesame yield parameters at Afgoi in the 2016 Hagai season (Trial 2).

Variety	Fertility (urea) kg ha^{-1}	Density plants hill^{-1}	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Plant population plants ha^{-1}	Plant height cm	Branches plant^{-1}	Capsules plant^{-1}
Humera	0	2	290	2051	138462	78.9	4.1	39.4
Humera	15	2	236	2051	138462	80.6	4.0	38.2
Humera	30	2	227	2564	129487	70.4	3.7	27.4
Local	0	2	719	2821	119231	106.2	5.0	89.9
Local	15	2	564	3333	103846	106.2	6.1	88.4
Local	30	2	619	3333	121795	105.1	5.2	73.9
Humera	0	4	233	2821	155128	80.5	3.8	39.4
Humera	15	4	210	2051	179487	76.2	3.4	28.2
Humera	30	4	324	2564	176923	80.8	3.5	43.8
Local	0	4	705	3590	214103	121.6	5.1	66.9
Local	15	4	385	2821	183333	97.4	4.8	55.3
Local	30	4	436	3077	200000	97.8	4.8	55.3
Humera	0	—	262	2436	146795	79.7	3.9	39.4
Humera	15	—	223	2051	158974	78.4	3.7	33.2
Humera	30	—	276	2564	153205	75.6	3.6	35.6
Local	0	—	712	3205	166667	113.9	5.0	78.4
Local	15	—	474	3077	143590	101.8	5.5	71.9
Local	30	—	528	3205	160897	101.4	5.0	64.6
Humera	—	2	251	2222	135470	76.6	3.9	35.0

Humera	—	4	256	2479	170513	79.2	3.6	37.1
Local	—	2	634	3162	114957	105.8	5.4	84.1
Local	—	4	509	3162	199145	105.6	4.9	59.2
Humera	—	—	253 B	2350 B	152991 A	77.9 B	3.7 B	36.1 B
Local	—	—	571 A	3162 A	157051 A	105.7A	5.2 A	71.6 A
—	0	—	487	2821	156731	96.8	4.5	58.9
—	15	—	349	2564	151282	90.1	4.6	52.5
—	30	—	402	2885	157051	88.5	4.3	50.1
—	—	2	443	2692	125214 bb	91.2	4.7 aa	59.6 aa
—	—	4	382	2821	184829 aa	92.4	4.2 bb	48.1 bb
LSD (Variety)			150	527	25088	10.2	0.4	9.2
LSD (Fertility)			183	645	30727	12.5	0.5	11.2
LSD (Density)			150	527	25088	10.2	0.4	9.2
R^2			0.77	0.74	0.81	0.81	0.86	0.91
CV (%)			50.0	26.3	22.3	15.4	12.9	23.5
Fertility (P>f)			0.4046	0.2500	0.8841	0.2936	0.5002	0.2810
Variety (P>f)			0.0409	0.0188	0.7324	0.0136	0.0166	0.0084
Variety x Fertility (P>f)			0.4205	0.8067	0.4694	0.6272	0.4190	0.5626
Density (P>f)			0.3978	0.6056	0.0002	0.8097	0.0414	0.0191
Density x Variety (P>f)			0.3602	0.6056	0.0542	0.7738	0.6004	0.0075
Density x Fertility (P>f)			0.9094	0.2102	0.9686	0.4449	0.2311	0.1840
Density x Variety x Fertility (P>f)			0.6376	0.9112	0.6743	0.4160	0.5494	0.8074

Table 4. Effect of planting population on yield parameters of two sesame varieties at Afgoi in the 2016/17 Deyr season (Trial 3).

Variety	Row width m	Plant population plants ha^{-1}	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Harvested plant population plants ha^{-1}	Plant height cm	Capsule height cm	Capsule length cm	Branches plant^{-1}	Capsules plant^{-1}
Humera	0.40	250000	201	825	173611	81.2	39.2	3.0	2.7	26.2
Humera	0.50	200000	489	1063	183333	75.1	43.0	3.1	2.0	23.3
Humera	0.60	167000	219	719	134722	81.4	42.2	2.8	2.6	24.3
Local	0.40	250000	554	2360	208333	110.7	72.0	2.6	3.2	26.5
Local	0.50	200000	321	1125	187500	77.0	52.0	2.7	4.0	29.2
Local	0.60	167000	314	1311	97222	90.6	53.8	2.8	4.2	27.3
Humera		—	303	869 B	163889	79.3 B	41.5 B	2.9 A	2.4 B	24.6
Local		—	396	1598 A	164352	92.7 A	59.3 A	2.7 B	3.8 A	27.7
—	0.40	250000	378	1592	190972 a	96.0 a	55.6	2.8	3.0	26.3
—	0.50	200000	405	1094	185417 a	76.1 b	47.5	2.9	3.0	26.3
—	0.60	167000	267	1015	115972 b	86.0 ab	48.0	2.8	3.4	25.8
LSD (Variety)			149	574	30181	12.9	7.1	0.3	1.1	13.7
LSD (Density)			182	703	36964	15.8	8.7	0.3	1.4	16.7
R^2			0.65	0.65	0.77	0.68	0.83	0.58	0.52	0.14
CV (%)			40.5	44.3	17.5	14.3	13.4	9.0	34.0	49.8
Variety (P>f)			0.1934	0.0178	0.9734	0.0420	0.0002	0.0404	0.0180	0.6270
Density (P>f)			0.2485	0.1903	0.0018	0.0546	0.1140	0.7996	0.7397	0.9967
Variety x Density (P>f)			0.0301	0.1088	0.1420	0.1814	0.0233	0.2900	0.4904	0.9318

Table 5. Effect of planting date on yield parameters of two sesame varieties at Afgoi in the 2016/17 Deyr season (Trial 4).

Variety	Planting date	Grain yield kg ha^{-1}	Stover yield kg ha^{-1}	Harvested plant population plants ha^{-1}	Plant height cm	Capsule height cm	Capsule length cm	Branches plant^{-1}	Capsules plant^{-1}
Humera	22-Oct	446	1671	195834	101.8	52.7	2.8	3.6	41.1
Humera	29-Oct	517	1399	206250	95.3	47.4	3.0	4.2	46.8
Humera	5-Nov	435	1102	196875	79.0	38.0	3.2	2.6	28.5
Local	22-Oct	577	1695	203125	99.0	57.4	3.0	5.0	43.5
Local	29-Oct	524	1575	233333	100.9	59.3	2.9	5.1	45.8
Local	5-Nov	505	1394	198958	93.5	55.1	3.0	3.4	32.8
Humera	—	466	1391	199653	92.0 A	46.0 B	3.0	3.4 B	38.8
Local	—	535	1555	211806	97.8 A	57.3 A	2.9	4.5 A	40.7
—	22-Oct	511	1683 a	199479	100.4 a	55.0 a	2.9	4.3 a	42.3 ab
—	29-Oct	520	1487 ab	219792	98.1 a	53.3 ab	3.0	4.6 a	46.3 a
—	5-Nov	470	1248 b	197917	86.3 b	46.5 a	3.1	3.0 b	30.7 b
LSD (Variety)		100	276	35170	6.3	6.2	0.2	0.8	11.2
LSD (Date)		122	338	43075	7.7	7.6	0.3	1.0	13.8
R^2		0.36	0.56	0.22	0.78	0.68	0.36	0.62	0.34
CV (%)		22.9	21.5	19.7	7.6	13.8	8.2	23.1	32.5
Variety (P>f)		0.1590	0.2243	0.4728	0.0675	0.0015	0.6810	0.0128	0.7174
Date (P>f)		0.6568	0.0467	0.4986	0.0028	0.0702	0.2043	0.0071	0.0715
Variety x Date (P>f)		0.5702	0.7039	0.8106	0.0853	0.2528	0.2402	0.7920	0.9192

Table 6. Sesame yield parameters of six varieties grown at Afgoi and Balad in the 2016/17 Deyr season (Trial 5).

Variety	**Location**	**Grain yield kg ha^{-1}**	**Stover yield kg ha^{-1}**	**Harvested plant population plants ha^{-1}**	**Plant height cm**	**Capsule height cm**	**Branches plant^{-1}**	**Capsules plant^{-1}**
Humera	Afgoi	381	1402	197917	90.3	85.0	3.00	42.1
Indian+G	Afgoi	510	1754	193750	100.3	87.1	2.67	40.8
Local	Afgoi	551	2019	200000	109.1	105.0	5.08	59.8
Nigerian	Afgoi	454	1119	200000	92.3	78.3	3.42	53.2
Setit	Afgoi	346	1242	209375	94.0	68.6	3.58	35.8
Yemeni	Afgoi	558	1748	197917	96.5	86.7	3.83	46.5
Humera	Balad	364	1239	98958	118.5	44.0	4.75	81.0
Indian+G	Balad	570	1521	104167	100.5	35.0	3.50	41.5
Local	Balad	460	1196	110417	117.0	52.5	5.50	52.5
Nigerian	Balad	438	1406	105208	102.8	40.5	4.25	65.3
Setit	Balad	357	1453	101042	120.3	47.8	4.25	66.5
Yemeni	Balad	635	1417	108333	101.8	49.5	5.25	46.5
Humera	—	372 CD	1320	148438	104.4	64.5 B	3.9 BC	61.5
Indian+G	—	540 AB	1638	148958	100.4	61.0 B	3.1 C	41.1
Local	—	506 ABC	1607	155208	113.0	78.8 A	5.3 A	56.1
Nigerian	—	446 BCD	1263	152604	97.5	59.4 B	3.8 BC	59.3
Setit	—	352 D	1347	155208	107.1	58.2 B	3.9 BC	51.1
Yemeni	—	597 A	1582	153125	99.1	68.1 AB	4.5 AB	46.5
—	Afgoi	467	1547	199826 a	97.1 b	85.1 a	3.6 b	46.3 b

—	Balad	471	1372	104687 b	110.1 a	44.9 b	4.6 a	58.9 a
LSD (Variety)		149	NS	19390	NS	12.5	1.1	NS
LSD (Location)		NS	NS	11195	8.2	7.2	0.70	10.6
R^2		0.45	0.56	0.92	0.55	0.88	0.55	0.47
CV (%)		31.1	26.4	12.5	13.5	18.8	27.1	34.2
Variety (P>f)		0.0132	0.2171	0.9624	0.2574	0.0220	0.0105	0.2118
Location (P>f)		0.9281	0.3928	0.0001	0.0672	0.0137	0.0293	0.0085
Location x Variety (P>f)		0.8819	0.0813	0.9018	0.2676	0.1388	0.8413	0.0895

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