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Optimizing Maize Planting Date, Plant Population, and Fertilizer Application Rates for Lesotho Subsistence Farmers

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I am submitting herewith a thesis written by Matthew Ryan Bruns entitled "Optimizing Maize Planting Date, Plant Population, and Fertilizer Application Rates for Lesotho Subsistence Farmers." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Sciences.

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Optimizing Maize Planting Date, Plant Population, and Fertilizer Application Rates for Lesotho Subsistence Farmers

A Thesis Presented for the

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Matthew Ryan Bruns

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DEDICATION

This thesis is dedicated to my wife Wendy, whose patience, guidance, and motivation was constant; to my parents, Linda and Duane, who always stressed the importance of a higher education; and to my sister, Amanda, who always set the example to which I try to hold myself.

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ABSTRACT

Due to perpetually low yields, smallholder farmers throughout Southern Africa plow increasingly large plots of land in an attempt to increase their household food security. However, extensive agriculture further depresses yields because expensive inputs are spread over a larger area, provides little soil cover, and results in high soil erosion rates. To address these challenges, farmers in the Kingdom of Lesotho are beginning to adopt conservation agriculture (CA) systems. Under CA and conventional tillage systems the optimum plant population, planting date, and fertilizer rates are unknown. The effects of field preparation, planting date, weed control strategies, plant populations, and nitrogen (N), phosphorus (P), and potassium (K) fertilizer application rates on maize yields at Maphutseng and Roma, Lesotho were investigated. During the 2009-2010 growing season two factorial experiments were conducted at Maphutseng: the first to determine the effects of tillage type, weed control methods, and planting date; the second to determine the effects of plant population density, N fertilizer application rate, and P fertilizer application rate on maize yield. During the 2010-2011 growing season, the effects of plant population, N, P, and K fertilizer application rates were studied using separate studies conducted on no-till fields at both study locations.

The planting date, tillage type, and weed control study found that planting in October attained the highest yields in both the tilled (7.32 Mg/ha) and no-till (10.25 Mg/ha) plots, and that in the tilled plots the glyphosate and hand hoeing weed control treatment resulted in the highest yields (7.79 Mg/ha). The plant population density study found that the 1 seeds/basin and 126 basins/plot treatment attained the highest yield

(11.57 Mg/ha). The fertilizer application rate study concluded that there was no significant yield gain above 50 kg N/ha (8.9 Mg/ha), 30 kg P_2O_5 [phosphorous pentoxide]/ha (2.16 Mg/ha), and 60 kg K_2O [potassium oxide]/ha (4.01 Mg/ha). These results illustrate that intensifying agriculture through the use of higher fertilizer rates and denser plant populations can result in household food security on less than 0.5 ha of land area, depending on household size.

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NOMENCLATURE

plants ha^{-1}	plants per hectare
t ha^{-1}	tons per hectare
kg ha^{-1}	kilogram per hectare
kg	kilogram
kg C-eq	kilogram of carbon equivalence
cm	centimeter
L ha^{-1}	liter per hectare
a.i.	active ingredient
basins $plot^{-1}$	basins per plot
seeds $basin^{-1}$	seeds per basin
grams $basin^{-1}$	grams per basin
m	meter
Mg ha^{-1}	megagrams per hectare
cobs ha^{-1}	cobs per hectare
cobs $plant^{-1}$	cobs per plant

LIST OF ABBREVIATIONS

CA	Conservation Agriculture
N	Nitrogen
P	Phosphorus
K	Potassium
SOM	Soil Organic Matter
FAO	Food and Agriculture Organization
OM	Organic Matter
GHG	Green House Gases
C	Carbon
SOC	Soil Organic Carbon
GLM	General Linear Model
LSD	Least Significant Difference
ANOVA	Analysis of Variance
SAS	Statistical Analysis Software
TSP	Triple Super Phosphate

1. INTRODUCTION

GENERAL BACKGROUND

As the world population continues to grow, food production comes under pressure for a new green revolution. Through the purchase and use of synthetic fertilizers, improved genetics, and precision planters and harvesters, affluent countries continue to produce excess food for export; however, the number of undernourished people in the world, currently estimated to be 900 million people, continues to increase. The problem of the disparities in the distribution of global food production is compounded by the fact that most of the undernourished peoples reside in countries with food deficits (FAO, 2008) and soils with low intrinsic fertility. The current world population is approximately 7 billion, and the yearly growth rate is approximately 77 million (U.S. Census Bureau, 2012). Currently, it is estimated that one in six people go to bed hungry most nights and survive on less than one dollar per day (Collier, 2007).

Sustainable intensification of food production must be a priority worldwide. However, due to the rising price of synthetic inputs it is often only the affluent countries that can afford sufficient amounts of fertilizers, herbicides, pesticides, fungicides, and mechanized farming equipment to adequately meet their food demands. The prohibitive cost of inputs and lack of environmentally sustainable planting tools leaves developing countries lacking in food production. It is these developing countries that are under the most pressure to improve crop yields. For example, Lesotho once had food security and even had surplus to export to mining operations in South Africa in the mid- to late-19th century (Showers, 2005). Currently, less than thirty percent of the food consumed in

Lesotho is produced within the country; this represents a decrease in production from the 1980s, when fifty percent of food consumed was produced in country. Overall, food production continues to decrease; Lesotho was the only country in southern Africa to produce less food in 2009 than in 2008 (World Food Program, 2012).

Approximately three-quarters of the farmland in sub-Saharan Africa is seriously degraded due to depletion of essential soil nutrients and erosion (CIMMYT, 2006). Erosion on degraded arable land further degrades these intrinsically low fertility soils; fertile topsoil is removed, exposing subsoil that is less fertile and insufficient to support the levels of crop growth and biomass needed to protect the soil from the high intensity rainfall common to Africa. Thus, the cycle of soil erosion and degradation continues (Blackie and Jones, 1993).

Small-holder farmers, in response to decreased yields on degraded lands, increase the area of cultivated land in hopes of producing more food; this act of increasing the area of land under cultivation is termed extensive agriculture. This type of agriculture limits the effect of applied inputs such as improved seeds and fertilizers, and makes it unlikely that these expensive added inputs will result in a greater grain harvest. The lack of available labor for typical land management makes extensive agriculture difficult to achieve due to the high labor requirements of these production systems. If the small-holder farmer does increase the arable land area and the rains are good that year, the lack of labor makes it unlikely that the small-holder family will have enough labor or time to control the weeds, thereby limiting total farm production to yields less than in drought years (Wall, 2007). In most cases this expansion of cultivated land area will cause devastating environmental effects intensified initially by ephemeral erosion and subsequent gully formation.

Tillage leads to soil degradation in almost all situations. Tillage buries the crop residues and speeds rates of organic matter decomposition. Crop residues, once removed from the surface by tillage or decomposition, can no longer suppress weeds or provide a slow release of nutrients. Tillage also destroys the soil structure and pore continuity which increases erodibility, decreases pore space, decreases water infiltration rates, and decreases macro fauna populations such as earthworms. Tilled soils have greater run-off rates during precipitation events, and have high carbon loss as carbon dioxide due to increased decomposition of the organic crop residue (Duiker and Beegle, 2006; Karlen et al., 1994; Kemper and Derpsch, 1981; Lal and Kimble, 1997).

Conservation agriculture (CA) systems provide methods to address these challenges and many of these harmful processes nearly cease. CA systems are based on three principles: 1) minimizing soil disturbance, 2) keeping year round residue over the soil surface, and 3) mixing and rotating crops (FAO, 2012; Harrington and Erenstein, 2005; Hobbs, 2007; Giller et al., 2009). Crop residues, when left on the surface, decompose more slowly, allowing for a slower and more continuous release of stored nutrients over subsequent growing seasons. The slower decomposition rates allow for a greater amount of carbon sequestration to take place due to a lower carbon dioxide (CO_2) efflux from the soil (Peterson et al., 1998). Crop residues also help to improve the soil by increasing aggregation or soil structure, porosity, cation exchange capacity, water holding capacity, by lowering the erodibility of the soil and by limiting soil temperature extremes

(Duiker and Beegle, 2006; Karlen et al., 1994; Kemper and Derpsch, 1981; Lal and Kimble, 1997)

Given the destructive impacts of tillage there is a need to investigate no-till and conservation agricultural production as a more sustainable and environmentally sound approach to food production. Before synthetic nitrogen (N) fertilizer production - a factor that contributed significantly to the green revolution - all farming was done using manure and longer crop rotations that contained N-fixing legumes, which lessened the need for annual tillage (Erisman et al., 2008). The heavy reliance on tillage for traditional agricultural production brings detrimental effects such as higher erodibility, and reduces soil and water conservation (Peigné et al., 2007). By implementing conservation tillage practices and focusing on strategies for long term sustainability, farming using no-till or CA should be able to produce more without negatively impacting the soil (Peigné et al., 2007). In developing countries, minimal external inputs coupled with an organic farming approach has been found to lead to yield increases; however, in affluent countries this approach often leads to lower yields when compared to traditional farming with heavy reliance on chemical fertilizers (Badgley et al., 2008; Stockdale, 2001). A positive development for CA is that there has been a trend of gradual growth in the successful adoption of CA systems in southern Africa by small-holder farmers (Twomlow et al., 2008). The use and adoption of no-till or conservation tillage agriculture could be a viable solution to the food crises occurring in Lesotho and other developing countries. Through research done in the United States and continued outreach programs focusing on CA systems in third world countries, the sustainability and viability of these systems may prove to be the key to increased food production and lowering the number of people that are malnourished.

Increasing crop production while protecting soil resources might be achieved in Lesotho through the development of a set of tested agronomic practices, including proper nutrient management application and timing, the use of improved cultivars, rotational cropping systems (particularly with leguminous plant species), and the use of cover crops between growing seasons. Often traditional African agriculture relies on extended fallow periods to restore soil fertility lost during continuous cropping (Blackie and Jones, 1993); the use of rotational cropping systems may be an alternative when farmers cannot allow land to lie fallow. In particular, legume rotations may be a viable option for restoring soil fertility and increasing crop yield in Southern Africa (MacColl, 1989). In addition to the rotation of crops, nutrient management is an essential part of agronomic management practices because of the mobility of macronutrients within the soil system. Finding the optimum fertilizer rates is essential to the agricultural productivity of Lesotho, particularly on a smallholder basis, because of the difficulties in obtaining affordable fertilizer sources (Heisey and Mwangi, 1996).

Fertilizer recommendations have not been scientifically determined in Lesotho and subsistence yields in Africa remained below 1 t ha^{-1} for decades, yet these low yielding crops can incorporate approximately 40 kg nitrogen (N) ha^{-1} in plant biomass (Sanchez, 1976). A fifteen year study on the carbon and nitrogen cycling in soils comparing inputs of organic and conventional inorganic fertilizers in a maize/legume crop rotation was conducted by Drinkwater et al. (1998) to determine the system best suited to minimize nutrient losses. Over the course of the study a maize-legume rotational cropping system with 39 megagrams (Mg) carbon (C) per hectare of plant residues returned to the soil increased soil carbon levels by 6.6 Mg C per hectare. The authors also used tracer studies to determine that higher levels of N were immobilized from leguminous organic sources than from inorganic fertilizers, which they found as an explanation for higher levels of nitrate (NO_3^-) leached from the conventional field (Drinkwater et al., 1998). While the higher rates of N immobilization reduce the available N in the short term, nutrients tied up in biomass and soil organic matter (SOM) may become available under the right conditions, whereas N from inorganic sources that is leached as NO_3^- or volatilized will not become available again in that system (Drinkwater et al., 1998).

Nitrogen inputs in Africa are dominated by inorganic fertilizer sources, despite the limited production of such synthetic sources in sub-Saharan regions. Most inorganic fertilizer use is concentrated in large-scale commercial production, of which there is very little in Lesotho (Smaling et al., 1993). Although organizations such as FAO may provide subsidies on inorganic fertilizers, in large part such resources are not utilized or are not used properly by smallholder farmers because of limited accessibility, prohibitive cost, and availability (Heisey and Mwangi, 1996). Giller and Wilson (2001) estimated the biological nitrogen fixation capacity of grain legumes to range between 25 and 100 kg N ha^{-1}; however, it has also been noted that grain legumes such as soybean [*Glycine max* (L.) Mem] store a large portion of this N within the soybeans, thus limiting the return of N to the soil after harvest, even when crop residues are maintained due to the removal of the grain at harvest (Sanchez et al., 1997; Drinkwater et al., 1998; Giller and Wilson, 2001). Comparing the recovery of N from additions of leguminous residues and inorganic fertilizers, Palm (1995) found that crops can take up 10% to 30% of nutrients contained in incorporated plant residues compared to 20% to 50% of inorganic fertilizer applications. Nel et al. (1996) conducted a long term maize-legume rotation trial in South Africa and found that maize yields were increased by 2 t ha^{-1} when planted in rotation with field peas (*Pisum arvense L.*) compared with unfertilized continuous maize. Jeranyama et al. (2007) found that groundnut (*Arachis hypogaea L.*) is another legume that can be used in rotation with maize. The authors' results from that study established that using a maize-groundnut rotation could reduce N fertilizer needs by as much as 64 kg N ha^{-1} and represents a 70% savings on N fertilizer (Jeranyama et al., 2007). Kumwenda et al. (2007) found that crop rotations can provide a change in the biological diversity of the soil, thus reducing the amount of pesticides and diseases in the system and helping to sustain productivity of the cropping system.

It has been demonstrated that CA crop production has a variety of benefits for soil quality, including but not limited to increased SOM, improved soil structure, and reduction in erosion rates. The use of CA technologies provides an opportunity to build soil N as well as SOM because of the improved nutrient cycling rates resulting from slower accessibility because of aggregate formation (Blevins and Frye, 1993). Despite the known benefits, the relationship between tillage and N cycling is complicated, which is why it is necessary to determine the optimal fertilizer rates and timing for a no-till system in sub-Saharan Africa. CA combined with organic fertilizer additions, such as manure or crop residues, has been shown to reduce the overall loss of soil N as compared to a soil without residue cover management over the course of a long-term study in Kenya (Kapkiyai, 1996). Eustice et al. (2009) also have shown that by adding organic amendments in concert with inorganic fertilizers results in an increase in SOM in both the labile and non-labile carbon fractions. This suggests that no-till management of soils in Africa can reduce the need for inorganic inputs. Alternately, in a study assessing the benefits of conversion to CA regarding greenhouse gas (GHG) emissions, Li et al. (2005) concluded that although the switch to CA increased the soil organic carbon levels, it also increased the flux of N_2O at levels that nullify the benefits from C sequestration and contribute to the GHG pool. The N_2O emissions were found to be between 0.006 and 0.02 kg N_2O for each kg of soil organic carbon (SOC) accumulated (Li et al., 2005). This is similar to reports by Marland et al. (2003), which indicated that after undergoing a switch from conventional tillage practices to CA practices, soils were found to have a change in N_2O emissions of 7 ± 15%. Marland et al. (2003) also reported that in these systems, for each kg of N fertilizer applied, 2.66 ± 1.33 kg C-eq. was generated and therefore lost from the system. The increased rates of N volatilization seen in these no-till studies underscores the importance of utilizing slow-release fertilizers where possible, and organic inputs such as crop residues and cover crops may be beneficial.

A common planting method that helps maintain crop residues, the Likoti or basin method, is being promoted in Africa; when using this method a small basin is dug that is approximately the width of the hoe and twice that size in length during the dry season. Once the first rains have begun, typically one to three seeds are planted at varying depths in the basin. Fertilizer, if available, is applied either before the rains begin or at planting and often again at a predetermined plant growth stage (Twomlow et al., 2007). This method effectively utilizes labor to prepare the land because the preparation is done in the dry season when little other agricultural work is being conducted. This method encourages timely planting, does not require the use and therefore payment for plowing, and can reduce the economic risk associated with maize production. Determining the optimum N, phosphorous (P), and potassium (K) application rates, planting date, and plant population densities, as well as demonstrating that CA helps to protect the soil and increases yields, may lead to the opportunity for food and economic security in southern Africa.

OBJECTIVES

The overall objective of this research was to find the optimum plant population density, N, P, & K fertilizer application rates, and to obtain the greatest maize yield in relation to these parameters. The study was also performed to investigate the effects of planting date, tillage type, and weed control treatment applications on maize yields in order to find the optimum CA system for maize production in sub-Saharan Africa. In this thesis we:

1) Evaluate planting date, tillage type, and weed control treatment applications in a CA maize production system.
2) Evaluate plant population densities in a CA maize production system.

3) Evaluate nitrogen, phosphorus, and potassium application rates in a CA maize production system.
4) Evaluate the efficacy of a subsample to estimate total yield.

THESIS ORGANIZATION

This thesis is divided into four studies. The first study is entitled “Planting Date, Tillage Type, and Weed Control Treatment Applications in a Maize Conservation Agriculture System” and its subsections are Introduction, Materials and Methods, Results and Discussion, and Conclusions. This study investigated the effect of planting date, tillage type, and weed control treatment applications on maize yield response in order to determine the optimum planting date, prove the efficacy of conservation agriculture systems, and determine the optimum weed control treatment application.

The second study is entitled “Plant Population Densities in a Maize Conservation Agriculture System” and its subsections are Introduction, Materials and Methods, Results and Discussion, and Conclusions. This study investigated the effects of plant population densities on maize yield response in order to determine the optimum plant population for maximizing maize yields.

The third study is entitled “Fertilizer Application Rates in a Maize Conservation Agriculture System” and its subsections are Introduction, Materials and Methods, Results and Discussion, and Conclusions. This study investigated the effects of N, P, and K fertilizer rates on maize yield response in order to determine the optimum fertilizer application rates to maximize maize yields.

The fourth study is entitled “Efficacy of a Subsample to Estimate Maize Yield in a Maize CA System” and its subsections are Introduction, Materials and Methods, Results and Discussion, and Conclusions. This study investigated the efficacy of a subsample to estimate maize yield as compared to sampling the whole plot. All references for this thesis appear in the List of References.

2. PLANTING DATE, TILLAGE TYPE, AND WEED CONTROL TREATMENT APPLICATIONS IN A MAIZE CONSERVATION AGRICULTURE SYSTEM

INTRODUCTION

Conservation agriculture (CA) systems are based on three principles: 1) minimizing soil disturbance, 2) keeping residue over the soil surface, and 3) mixing and rotating crops (FAO, 2012; Harrington and Erenstein, 2005; Hobbs, 2007; Giller et al., 2009). Across southern Africa, experimentation to support the promotion of CA is ongoing, but locally generated scientific data is scarce (Thierfelder and Wall, 2007). The term conservation tillage is defined as any cropping system that maintains at least thirty percent of the crop residues on the surface directly following planting (CTIC, 2007). No-till is a type of CA, and can be defined as direct seeding into the residue of the previous crop with the least amount of disturbance to the soil, and relies on cover crops and/or herbicides for weed control (Brady and Weil, 2008; Blevins and Frye, 1993). The adoption of these systems is fueled by worldwide demand to attain food security and in hopes of combating the ongoing problems with soil degradation, erosion, and reduced fertility (Blevins and Frye, 1993). This study, in combination with a planting population study and a fertilizer application study, seeks to gather scientific data on how planting date, tillage type, and weed control treatment applications can affect the yield of maize in a CA system.

Achieving high maize yields is a function of many variables including climate, soil fertility, and agronomic management practices such as planting date, fertilizer rates, and irrigation rates (Ramankutty et al., 2002). No-till planting of maize has been demonstrated to match or outperform the yields achieved by maize planted with conventional tillage (Lawrence et al., 1994; Lueschen et al. 1991; Moschler et al., 1972; Shear and Moschler, 1969). The ability of no-till maize to reach high yields has been attributed to better moisture control at the soil surface, better water infiltration properties, temperature control, and more favorable nutrient supply (Aase and Tanaka, 1987; Schillinger and Bolton, 1993, and Wilhelm et al., 1986). A study conducted in a semi-arid environment in Australia concluded that using no-till resulted in a greater maize yield when compared with reduced till fallow and conventional till fallow treatments (Lawrence et al., 1994). Wilhelm et al. (1986) found a positive linear response between maize yield and the amount of surface residue in a no-till system. Similar to the results from the study performed by Lawrence et al. (1994), an increase in maize yield of 6.3 Mg ha^{-1} was observed in a no-till system when compared with a moldboard plow system during a dry year by Lueschen et al. (1991). Eckert (1984) found that no-till planted maize yielded more in drier years and conventional tillage planted maize yielded more in wetter years, this finding is supported by other literature reporting lower yields from poorly drained soils and higher yields from well drained soils for no-till planted maize (Dick and Van Doren, 1985; Ismail et al., 1994; Wagger and Denton 1992). Kapusta et al. (1996) conducted a 20 year study on the effects of tillage systems on maize yield and concluded that over the course of the study there was no difference in maize yields between no-till, reduced till, and conventional tillage. Ketcheson (1990) saw similar results in a study conducted in Ontario, Canada; however, in that study it was found that both no-till and reduced tillage attained lower maize yields than conventional tillage and was attributed to the increased difficulty of root penetration in the medium to fine textured soils.

The importance of planting date and its impact on yield potential has been well demonstrated in previous literature (Anderson et al., 2001; Bruns and Abbas, 2006; Epplin and Pepper, 1998; Lauer, 2001; Lauer et al., 1999; Nielsen et al, 2002; Swanson and Wilhelm, 1996). Cardwell (1982) investigated maize yields from Minnesota from 1930 to 1979 and found an 8% yield increase which resulted from a ten day shift toward earlier planting and was equal to a yield increase of 0.031 Mg ha^{-1} for each additional day that was added to the growing period due to earlier planting. The highest grain yields are typically observed where the growing season is the longest and soil moisture is not limiting; by planting earlier, the length of time the plants are exposed to favorable growing conditions and the accumulation of biomass are increased (Kucharik, 2006). In a study of maize yield data collected between 1979 and 2005 in 12 central U.S. states, the relationships among state level monthly climate variables including temperature and precipitation, maize yields, and planting dates were quantified; after investigation as to whether earlier planting was partially responsible for rising yields during the study period, it was concluded that a yield increase of 0.06 to 0.14 Mg ha^{-1} could be attributed to each additional day of earlier planting, and also found that the states most affected by planting date were those located on the northern and western edge of the study area

(Kucharik, 2008). According to previous literature, it is expected that the areas that would experience the largest impact on maize yields from earlier planting would be those areas that are limited by temperature or precipitation (Thompson, 1988; Darby and Lauer, 2002; Hu and Buyanovshy, 2003; Lobell and Asner, 2003).

While the effect of early planting on maize yields is clear from the literature, two of the most important production constraints on smallholder farmers can be exacerbated by a longer growing season: these are weed control and the shortage of labor. A smallholder farmer can spend 50-70% of the total labor cost on weed control, which is typically hand-hoeing (Weber et al., 1995; Chikoye et al., 2002). Chikoye et al. (2004) state that due to inefficient and untimely weed control, crop yields are generally low despite the high input of energy and resources used for weed removal. Weeding is often postponed due to conflicts with other farm activities, allowing weeds to mature, requiring more time and labor to remove them, and resulting in varying degrees of yield losses, depending on the critical period of weed competition (Chikoye et al., 2004). Timely weed control is essential to maximizing maize yields, this is supported by a study conducted by Usman et al. (2001), which found that removing weeds too late can result in yield losses of up to 83%. Weed control can be an issue even when using chemical methods, as the length of herbicide effectiveness after application can be affected by soil type, rate of application, and environmental conditions (Akobundu, 1987). Weed species, densities, and associated interactions may influence maize yield loss; with the weed density above which the crop yield is reduced defined as the competitive threshold (Young et al., 1984; Oliver, 1988; Kropff et al., 1992; Scholes et al., 1995; Fausey et al., 1997). Previous research has found that the detrimental impact weeds have on maize yield varies depending on the species of weed. Yield losses observed by Ghosheh et al. (1996) found Johnsongrass (*Sorghum halepense L.*) density above the competitive threshold was able to decrease maize yield by as much as 46.6%, and Knezevic et al. (1994) demonstrated maize yield losses of up to 34% for redroot pigweed (*Amaranthus retroflexus L.*) densities above the threshold.

Weed control is a factor in the tendency towards later planting by smallholder farmers in Lesotho because they will wait to plant until after first flush of weeds following tillage occurs, so that those can be killed prior to the emergence of the crop. Delayed planting may also occur in the hopes that any pests coming into an area targeting the maize crop will attack the crops of other farmers nearby that chose an earlier planting date and whose crop is more mature, and then move on. Insects can also be a deciding factor in later planting because farmers want to ensure that the silking of the maize plants is timed for the hatching and migration patterns of pollinators. The factor of greatest consequence in later planting, and especially important for maize planted with conventional tillage, is that of the seasonal precipitation patterns in Lesotho, which has a dry winter season and a wet summer season. Smallholder farmers do not want to risk wasting seed by planting based on the expectation that the rains will come soon, and so will wait to plant until the growing season precipitation has actually commenced. Altogether, the variety of influences on the decision making of smallholder farmers in Lesotho makes the objectives of the current study in determining optimum planting date and weed control treatments for those stakeholders particularly complicated.

MATERIALS AND METHODS

Site Description

The experimental research site at Maphutseng, Lesotho, southern Africa, is located at S 30°12’49.8” and E 27°29’41.3” at an elevation of 1455 meters. The soil series name for this site is Phechela series. The soil is classified as a fine, montmorillonitic, mesic, Typic Pelludert. Soil samples were taken and pH (6.63) determined using a 1:1 soil:water ratio (Kalra, 1995), and the buffer pH (6.15) was determined using the Mehlich Buffer pH method (Mehlich, 1976). All other elemental analyses were determined using Mehlich-1 extractant and analyzed for concentration using ICP (Mehlich, 1953) (Table 19 in Appendix). Temperature and precipitation data was obtained from the Maseru International Airport, Lesotho. The total amount of precipitation from October 17, 2009 until harvest on July 7, 2010 was approximately 560 mm and the average temperature for the growing season (October through June) was 20 ^{o}C (NCDC, 2012). Prior to this study this field had been in a long term fallow/pasture for approximately 20 years.

Experimental Design

This study evaluated three planting dates, two tillage types, and four types of mechanical and chemical weed control treatments resulting in a total of 24 treatments (Table 1 and Table 20 in Appendix). The target planting dates were October 17th, 2009, November

17th, 2009, or December 17th, 2009. The two tillage treatments were tilled and no-till. The four weed control treatment applications were hand hoeing, one pre-emergence application of glyphosate (Roundup®, Monsanto) at 3 liters of a.i. ha^{-1} followed by hand hoeing, one pre-emergence application of glyphosate and flumetsulam and S-metolachlor (Bateleur® Gold, Syngenta) both applied at 3 L of a.i. ha^{-1}, and glyphosate, whereby glyphosate was applied as needed at 3 L a.i. ha^{-1} post emergence. The treatments were assigned in a randomized block design with four blocks and in a factorial treatment design with 24 treatment combinations giving a total of 96 experimental units (Table 20 in Appendix for plot plan). The plot size for each treatment was 10 m by 3 m. The chemical weed control treatments were applied once to each plot on December 18th, 2009 which resulted in a pre-emergence application for the December 17th planting date and post-emergence for the October and November planting dates. The glyphosate treatment had glyphosate applied as needed. Hand hoeing was performed as needed in all treatments that contained hand hoeing.

The plots that used no-till as the tillage type were planted using the Likoti or basin method; a common planting method where a small basin is dug that is approximately the width of the hoe and twice that size in length during the dry season. The conventional tillage plots were tilled using a mold board plow in October 2009 and were planted using an ox drawn planter. The flumetsulam and S-metolachlor and glyphosate were applied at a rate of 3 liters of a.i. ha^{-1} individually using a knapsack sprayer. All plots within this study were planted with Pioneer hybrid 31G54 maize, a target population of 29,600 plants per hectare, and were harvested on July 10th, 2010.

Table 1. Treatments applied to plots for the planting date, tillage type, and weed control treatment application study at the Maphutseng, Lesotho site during the 2009-2010 growing season. [1]Likoti are small basins approximately the width of a hoe and twice that size in length in which several seeds are typically planted at varying depths.

Tillage treatments	Planting Date	Weed control treatments
Tilled (conventional)	10/17/2009	Hand Hoeing
No-till (Likoti)[1]	11/17/2009	Glyphosate & Flumetsulam and S-metolachlor
	12/17/2009	Glyphosate & Hand Hoeing
		Glyphosate

Measurements

The whole plot was hand harvested and grain weight and percent grain moisture measured in order to calculate maize yield corrected to a moisture content of 15.5% on a mass/mass basis.

Analysis of the Data

The General Linear Models (GLM) procedure was used to analyze the data for main effects and interactions. Means were separated using Fischer's protected least significant difference (LSD), using an *a priori* method P<0.10 (SAS Institute, 2009). Data was screened using Grubb's test for outliers to identify any maize yield that was outside of the normal distribution or two standard deviations (Snedecor and Cochran, 1992). No outliers were found.

RESULTS AND DISCUSSION

There was an effect on maize yield found from the tillage type and the planting date (Table 2). There were interactions between tillage type and both planting date and weed control treatment at an alpha=0.1. Due to these interactions the data was split into the two different tillage types and GLM was used again to analyze the data separately. The statistical results for the tilled plots illustrate that planting date and weed control treatment affected the maize yield for the tilled plots (Table 3). Also, there were interactions between planting date and weed control and weed control treatment and replication that had an effect on the maize yields.

The first planting date, October 2009, resulted in the greatest yield for the tilled plots, attaining 7.32 Mg ha^{-1}, followed by the third planting date, December 2009, at 7.02 Mg ha^{-1}. The second planting date, November 2009, only achieved a yield of 5.99 Mg ha^{-1} for the tilled plots (Figure 1). The total amount of precipitation received from planting to harvest by each planting date ranged from 560 mm to 452 mm with the October planting date receiving the most total precipitation; however, the October planting received the least amount of precipitation between planting dates (44 mm), and the December planting received the most with 99 mm of precipitation between planting and the end of the month (Table 4, Figure 2, NCDC, 2012). The November planting received 64 mm of precipitation before the December planting date.

Weed control treatment had an effect on maize yield (Table 3) and it was found that a combination of glyphosate and hand hoeing were the most effective weed control treatment, yielding 7.79 Mg ha^{-1} which may be contributed to the mechanical weeding that was done for this treatment.

By continually suppressing weeds throughout the growing season competition for nutrients, water, and light was reduced compared to the other treatments. The other three weed control treatments did not differ from one another, but were different from the glyphosate and hand hoeing treatment.

Table 2. Statistical results for both tilled and no-till plots from the planting date, weed control treatment and tillage type study conducted at Maphutseng, Lesotho during the 2009-2010 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Yield (Mg ha^{-1})	Pr>F Value
Tillage Treatment	1		0.0011
Till (mold board plow)		6.78	
No-till		7.86	
Planting Date	2		<0.0001
October		8.78	
November		5.48	
December		7.69	
Weed Control Treatment	3		0.4090
Replication	3		0.4149
Till*Date	2		<0.0001
Till*Weed Control Treatment	3		0.0871
Till*Replication	3		0.1544
Date*Weed	6		0.1923
Date*Replication	6		0.1550
Weed*Replication	9		0.5125

Table 3. Statistical results for tilled plots from the planting date, weed control treatment and tillage type study conducted at Maphutseng, Lesotho during the 2009-2010 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Yield (Mg ha^{-1})	Pr>F Value
Planting Date	2		0.0504
October		7.32	
November		5.99	
December		7.02	
Weed Control Treatment	3		0.0824
Hand Hoeing		6.62	
Glyphosate & Hand Hoeing		7.79	
Glyphosate & Flumetsulam and S-metolachlor		6.27	
Glyphosate		6.44	
Replication	3		0.3394
Date*Weed	6		0.0967
Date*Rep	6		0.2433
Weed*Rep	9		0.0974

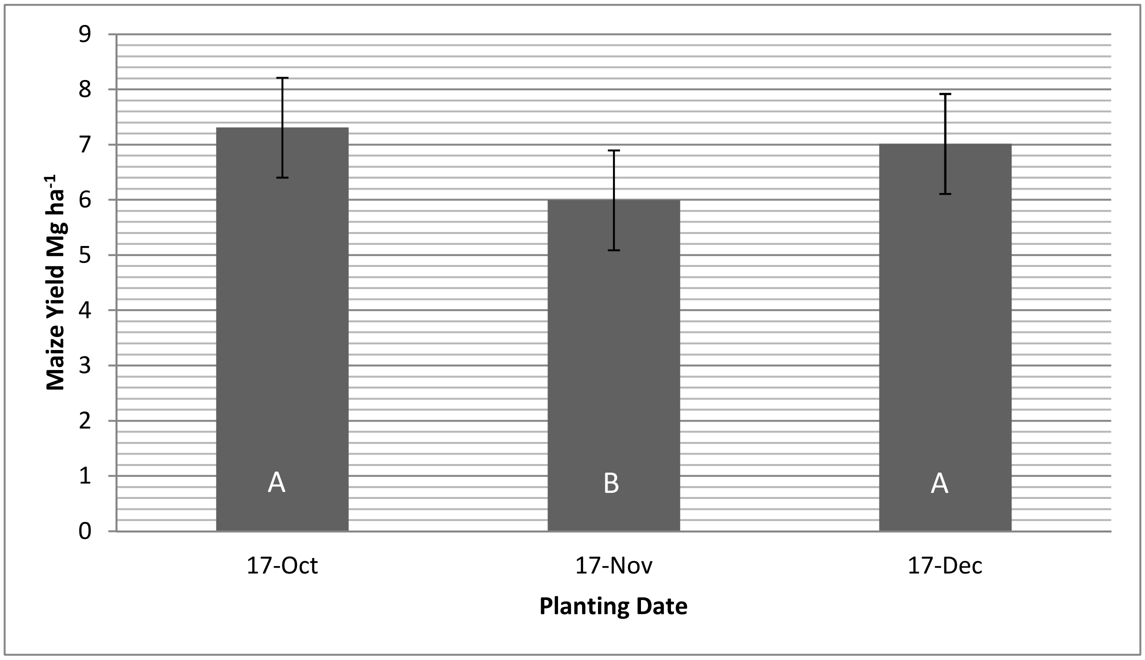

Figure 1. Effect of planting date on maize yield in tilled plots from the planting date, weed control treatment, and tillage type study conducted at Maphutseng, Lesotho during the 2009-2010 growing season. Treatments that have the same letter are not significantly difference at an alpha=0.1. Error bars are the LSD value attained from statistical analysis.

Table 4. Cumulative precipitation received for each planting date and the amount of precipitation received by each planting date before the subsequent planting date. Data collected at Maseru International Airport, Lesotho (NCDC, 2012).

Planting Date	Total precipitation from planting to harvest (mm)	Precipitation from previous planting date to planting date (mm)
October 17 2009	560.07	
November 17 2009	516.38	43.69 (Nine precipitation events)
December 17 2009	452.37	64.01 (Five precipitation events)

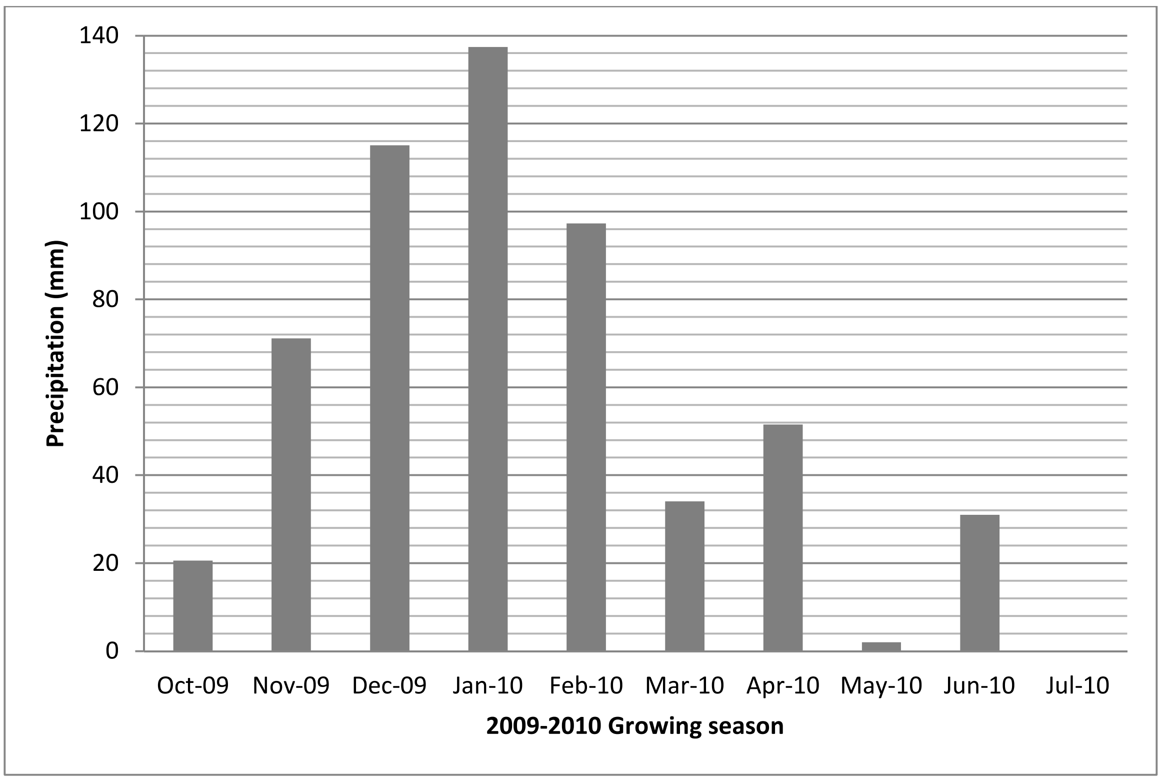

Figure 2. Total amount of precipitation by month for the 2009-2010 growing season. Total growing season (October through June) precipitation was 560 mm. Data was collected at the Maseru International Airport (NCDC 2012).

The yields of these treatments are as follows; hand hoeing 6.62 Mg ha^{-1}, glyphosate and flumetsulam and S-metolachlor 6.27 Mg ha^{-1}, and RR 6.44 Mg ha^{-1} (Figure 3). The data displayed an interaction between planting date and weed control treatment (Table 3) on maize yield; Figure 4 illustrates the effect of planting date and weed control treatment on maize yield in the tilled plots.

For no-till plots, planting date and replication had an effect on maize yield and an interaction between planting date and the replication (Table 5). The yields attained from the no-till plots based on the planting date follow the same pattern as the tilled plots (Figure 5); the first planting date had the highest yield (10.25 Mg ha^{-1}) followed by the third planting date (8.36 Mg ha^{-1}), and the second planting date had the lowest yield (4.97 Mg ha^{-1}) with all three planting dates being statistically different from one another.
The results of this study agree with the literature; only one planting date of the three resulted in the no-till plots having lower maize yields. This correlates with Lawrence et al. (1994), who found that conservation tillage compared with a mold board plow system resulted in greater maize yields. The reduced yield seen from the no-till plots that were planted on November 17th, 2009 agrees with Eckert (1984), who concluded that the amount of precipitation received is correlated with maize yield when comparing no-till systems with conventional tillage systems. Thompson (1986, 1988) also concluded that monthly temperature and precipitation affect maize yields.

The effect of planting date was significant for both the tilled and no-till plots, and it was illustrated that an early planting date will increase maize yield in both systems, except for the November 17th, 2009 planting date which resulted in the lowest yields

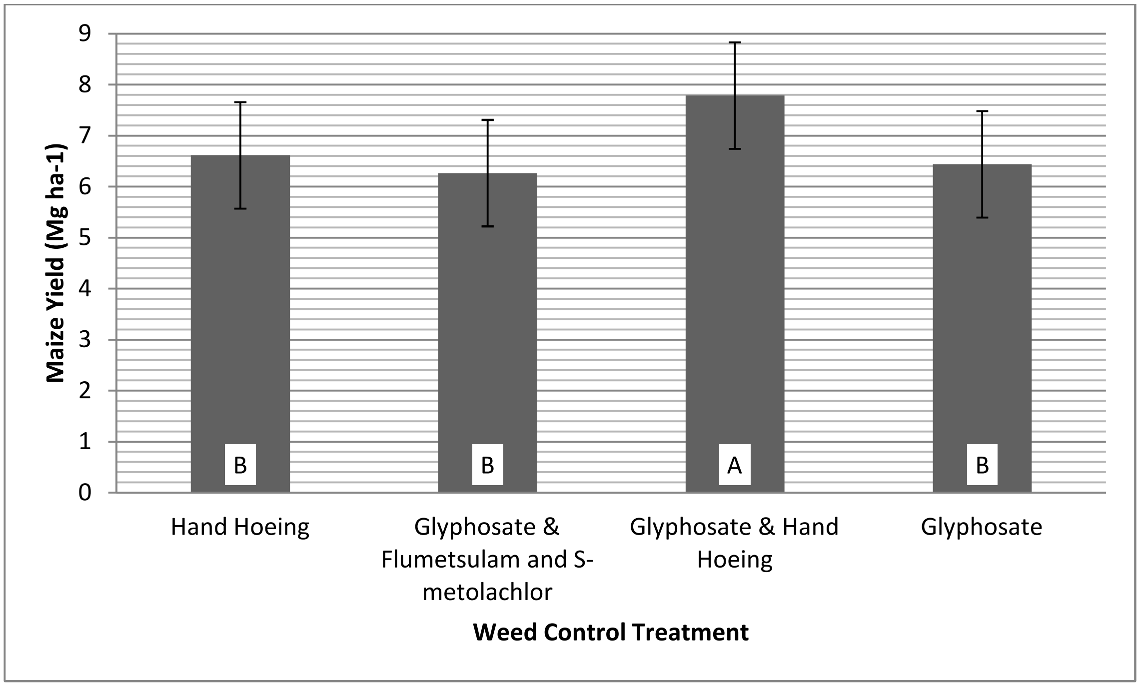

Figure 3. Effect of weed control treatment on maize yield in tilled plots during the 2009-2010 growing season at the Maphutseng, Lesotho research site. Treatments that share the same letter are not significantly different at an alpha=0.1. Error bars are the LSD value attained from statistical analysis.

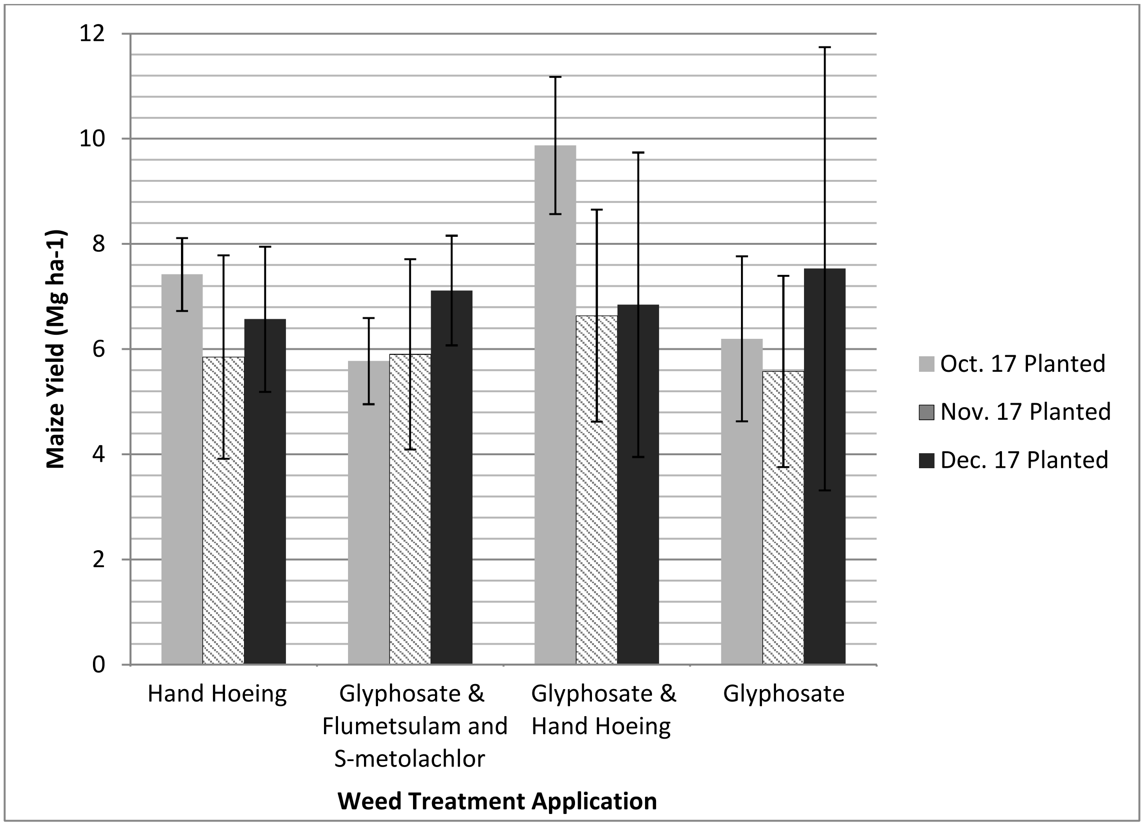

Figure 4. Effect of weed control treatment and planting date on maize yield from the tilled plots at the Maphutseng, Lesotho research site during the 2009-2010 growing season. Error bars are the standard deviation.

Table 5. Statistical results for the no-till plots at the Maphutseng, Lesotho research site based on maize yield data from the 2009-2010 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Yield ($Mg\ ha^{-1}$)	Pr>F Value
Planting Date	2		<0.0001
October		10.25	
November		4.97	
December		8.36	
Weed Control Treatment	3		0.2193
Replication	3		0.0522
Date*Weed	6		0.5991
Date*Rep	6		0.0148
Weed*Rep	9		0.2568

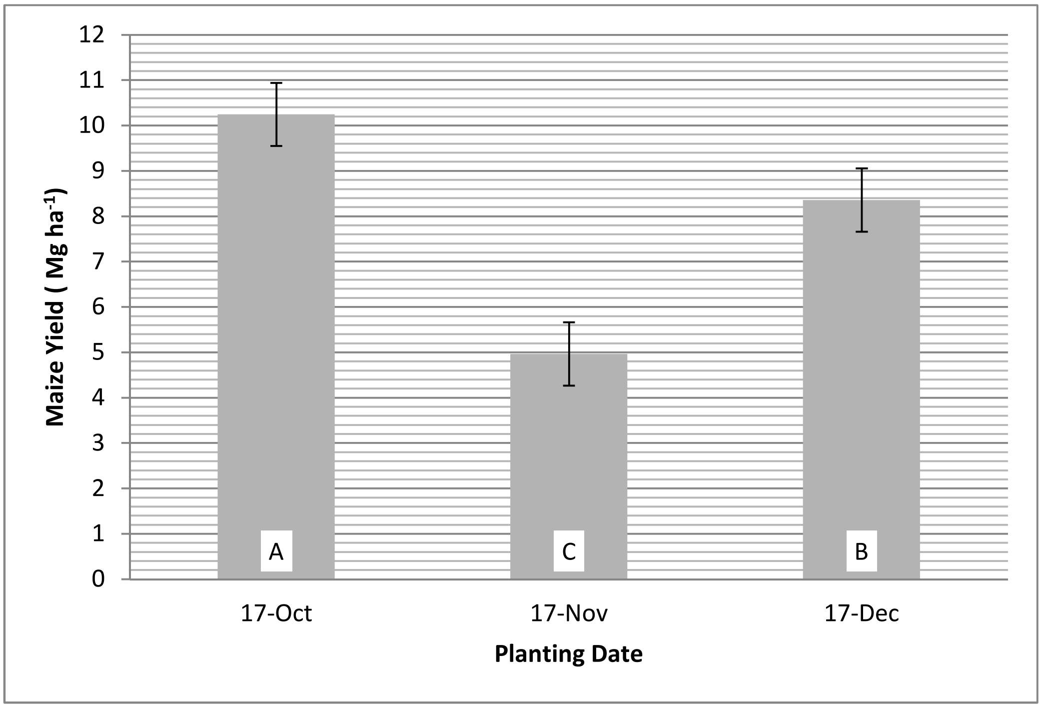

Figure 5. Effect of planting date on maize yield from the no-till plots at the Maphutseng, Lesotho research site during the 2009-2010 growing season. Treatments that share the same letter are not significantly different at an alpha=0.1. Error bars are the LSD value attained from statistical analysis.

recorded in either system; 5.99 and 4.97 Mg ha^{-1} for the tilled plots and no-till plots, respectively. The low yields in both the no-till and tilled plots for the second planting date were likely the result of oversaturation from precipitation events, including 9 precipitation events between the October and November planting dates resulting in a total of 44 mm of rain, and 5 precipitation events between the November and December planting dates resulting in an additional 64 mm of precipitation (Table 4). This trend of increasing precipitation explains the low yields seen from the second planting date and the result that the tilled plots achieved higher yields than the no-till plots for the second planting date supports this explanation. Tilled fields often produce more in wet years and no-till fields produce more in drier years (Eckert, 1984). This finding is supported by the literature; similar to Cardwell (1982), who found that earlier planting increases maize yield. The findings of this study also support other studies which suggest that early planting can result in increases in maize yield, but is also dependent on other climate variables such as precipitation (Thompson, 1986, Kaylen and Koroma, 1991, Lauer et al., 1999; Kucharik, 2008).

The result that weed control treatment only had a significant effect on maize yield for the tilled plots supports the findings of Erbach and Lovely (1975) among many other researchers, who concluded that the increased surface residue seen in no-till/conservation systems increased weed suppression and increased herbicide efficacy, thereby reducing herbicide application rates. The glyphosate and hand hoeing treatment achieved the highest yield in the tilled plots at 7.79 Mg ha^{-1}, and the glyphosate treatment achieved the highest yield in the no-till plots at 8.36 Mg ha^{-1}, which indicates these methods of weed control have a chance of being adopted over simple hand hoeing; this is supported by the findings of Chikoye et al. (2002), who reported that up to 70% of total labor was spent on weed control. The low yields from the November planting date in both tilled and no-till plots are also a result of the timing of herbicide application and tillage. The plots were tilled in October and this provided a sufficient suppression of weeds for that month. The planting in November, in both the tilled and no-till plots, did not have any additional management to suppress weeds and resulted in competition between the maize and weeds, contributing to the low reported yields. Herbicide application was started in December for all treatments and for the hand hoeing, glyphosate and hand hoeing, and glyphosate treatments it was continued as needed for the remainder of this study which resulted in greater yields in the December versus the November planting date.

CONCLUSION

The results of this study illustrate that, in general, no-till systems can produce greater maize yields than conventional tillage depending on planting date and weed management. In this study, planting in the month of November resulted in the lowest maize yields for both the tilled (5.99 Mg ha^{-1}) and no-till plots (4.97 Mg ha^{-1}), demonstrating the importance of climate variability, timing of herbicide application, and timing of tillage in maize production. Weed control treatment was not found to have a significant effect on maize yields in the no-till plots due to weed suppression from crop residue cover. The weed control treatment had a significant on maize yields in the tilled plots, with the glyphosate and hand hoeing treatment achieving the greatest yield (7.79 Mg ha^{-1}); it is therefore suggested that smallholder farmers who are using conventional tillage should use glyphosate and hand hoeing to attain the greatest yield. The use of hand hoeing cannot be undermined, and should continue to be a permanent weed control strategy in the management of smallholder farms. Due to the lack of replicated scientific studies, further research is needed to verify these results, and may then begin to allow for simple recommendations to be made throughout the region for planting date, tillage type, and weed control treatment applications.

3. PLANT DENSITIES IN A MAIZE CONSERVATION AGRICULTURE SYSTEM

INTRODUCTION

Plant population effects on growth and yield have been well established in the literature (Hunter, 1978; Daynard and Muldoon, 1981; Phipps et al. 1981; Pinter et al., 1990; Bavec and Bavec, 2002; Muhammad et al., 2010). Norwood and Currie (1996) found that maize yields increased with increasing plant density up to 44,500 plants ha^{-1}. Other studies have reported increases in maize yield with plant densities as high as 60,000 plants ha^{-1} (Norwood, 2001). The effect of increasing plant populations may only be valid above certain thresholds, however, as Havlin and Lamm (1988) reported no yield increases from increasing plant densities in maize with lower plant populations ranging from 21,000 to 37,100 plants ha^{-1}. Alternately, Bavec and Bavec (2002), studying higher plant population densities ranging from 70,000 to 130,000 plants ha^{-1} found that increases to plant density not only increases maize yield, but can also change cob characteristics; cob length, weight of 1000 kernels, number of kernel rows, and number of kernels per row were all significantly affected by an increase in plant density. Maximum grain yields and yield response to applied N were reported to be attained with a maize plant population of 62,000 plants ha^{-1} (Sharpiro and Wortmann, 2006). Although there is much research presented in the literature on the importance of plant population to achieving greater yields, there is very little research reported across southern Africa, especially in the Kingdom of Lesotho, Africa. Therefore, a plant population study was conducted at

Maphutseng in Lesotho, Africa to determine the effect of plant density on maize yields. As part of this study, the effect of seeds $basin^{-1}$ and basins $plot^{-1}$ was investigated to determine if there was a significant effect on maize yield from the treatments applied to attain the target populations. The main objective of this study was to determine optimum plant densities for no-till maize, and to add to the existing scientific data so that recommendations are available for this region.

MATERIALS AND METHODS

Site Description

The research site is located in Maphutseng, Lesotho, southern Africa, at S 30°12’49.8” and E 27°29’41.3” at an elevation of 1455 meters. The soil series name for this site is Phechela series. The soil is classified as a fine, montmorillonitic, mesic, Typic Pelludert. Soil samples were taken and pH (6.63) determined1:1 soil:water ratio (Kalra, 1995), and the buffer pH (6.15) was determined using the Mehlich buffer pH method (Mehlich, 1976). All other elemental analyses were determined using Mehlich-1 extractant and analyzed for concentration using ICP (Mehlich, 1953) (Table 19 in Appendix). Temperature and precipitation data was obtained from the Maseru International Airport, Lesotho. The total amount of precipitation received during the 2010-2011 growing season was 97 mm and the average temperature was 15 ^{o}C (measured at the airport) (NCDC, 2012). Prior to this study this field had been in a long term fallow/pasture for approximately 20 years.

Experimental Design

This study evaluated five planting populations which are as follows: 15,556; 28,000; 31,111; 46,667; and 56,000 plants ha^{-1}. All plots within this study were planted with Pioneer hybrid 31G54 maize and were planted on November 26, 2010. Each treatment consisted of one of the planting populations and all treatments were assigned in a completely randomized block design with four replications of 5 treatments giving a total of 20 experimental units (Table 21 in Appendix). The plot size for this treatment was 10 by 4.5 meters. In order to attain our target populations, the number of basins $plot^{-1}$ and the number of seeds $plot^{-1}$ were calculated based on the area of each plot, and it was found that either 70 basins $plot^{-1}$ or 126 basins $plot^{-1}$ would reach the target populations, depending on the target population and number of seeds $basin^{-1}$. The number of seeds that were placed in each basin ranged from 1 to 3 seeds depending on the target population and number of basins $plot^{-1}$ (Table 6). The row spacing for each 10 by 4.5 meter plot was dependent on the target population. To achieve the higher target plant populations using the Likoti planting system, the interrow spacing was halved, resulting in the higher target populations being planted with 45cm row spacing and 126 basins per plot, while lower target populations had an interrow spacing of 90 centimeters, with 70 basins per plot (Figure 6). The adjustment to row spacing in the higher populations was to accommodate for the plot size - each plot had five rows going across the plot width and 14 going down the plot length, with the rows in the 126 basins per plot treatments being split and offset in order to allow space between basins. All plots for the plant population study received an herbicide application of glyphosate, which was applied pre-plant at 3 L active

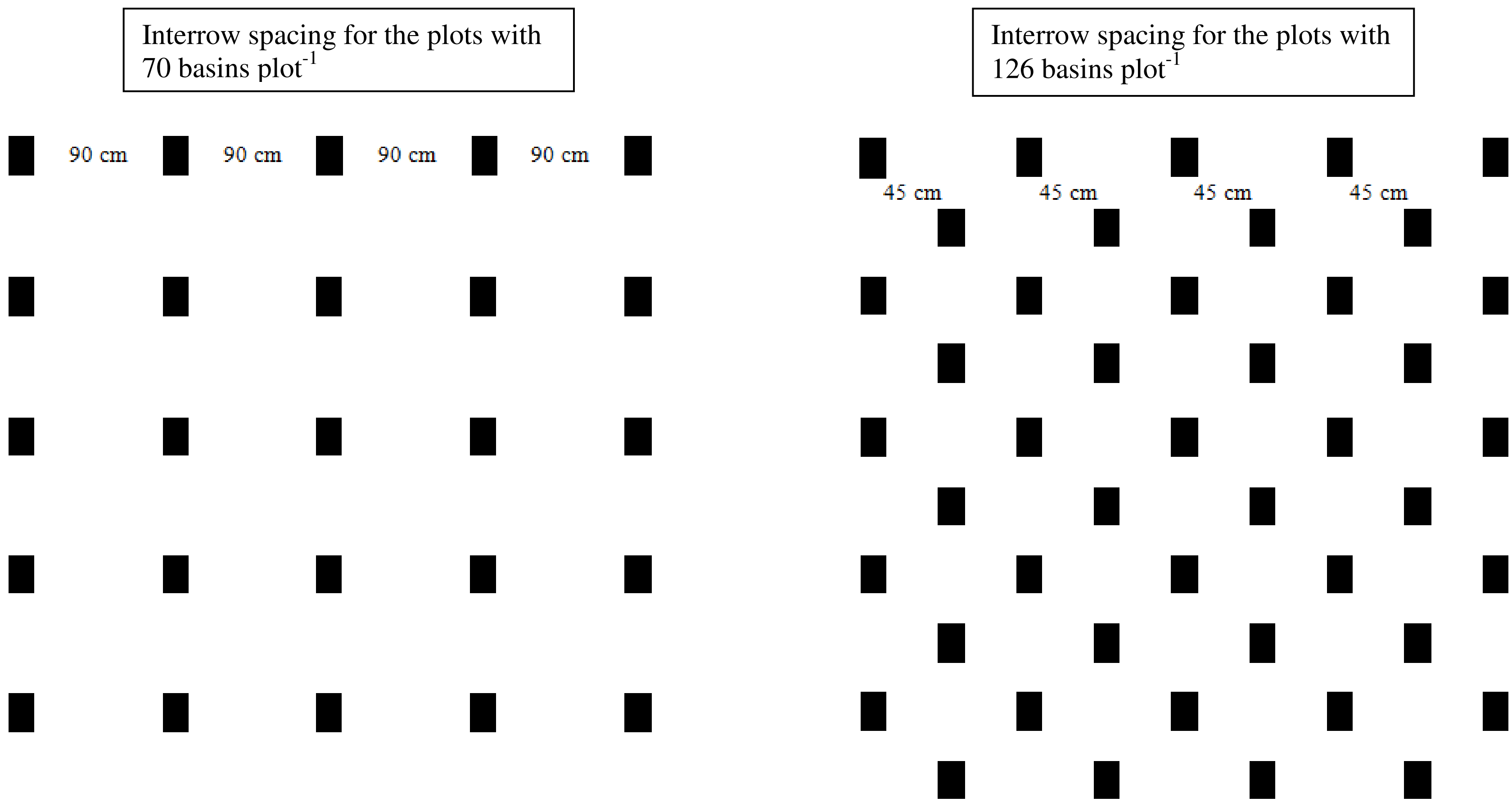

Figure 6. Difference in interrow spacing for the plant population experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. The black squares represent a basin within the plot. This figure illustrates the five rows across the width of the plot and five rows along the plot length from both the plots that have 70 basins and the plots that have 126 basins.

Table 6. Plant density study treatment yields from the 2010-2011 growing season, with corresponding seeds basin^{-1} and basins plot^{-1} used to attain the target populations at the Maphutseng, Lesotho site.

Plant Population Treatment} Target Population (plants ha^{-1})	Seeds basin^{-1}	Basins plot^{-1}	Measured Population (plants ha^{-1})
1} 15,556	1	70	23,392
2} 31,111	2	70	34,113
3} 46,667	3	70	43,372
4} 28,000	1	126	35,770
5} 56,000	2	126	42,787

ingredient (a.i.) ha^{-1} and a fertilizer application. Table 7 lists the fertilizer rates and the equivalent kg ha^{-1} for N, P, and K fertilizer.

Measurements

All plots within this study were hand harvested. Ear weight, stover weight, grain moisture and the number of plants were measured in the middle three rows of each plot in order to calculate the maize yield, corrected for a moisture content of 15.5% on a mass/mass basis.

Table 7. Fertilizer application rates in grams $basin^{-1}$ and kilograms ha^{-1} for the plant density study at the Maphutseng, Lesotho site during the 2010-2011 growing season.

Basins $plot^{-1}$	Fertilizer (g 3:2:1(25) $basin^{-1}$)	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
70	62	117	78	39
126	34	112	74	37

Analysis of the Data

The GLM procedure was used to analyze the data at an alpha=0.1 for main effects. Means were separated using Fischer's protected least significant difference (LSD), using an *a priori* method P<0.1 (SAS Institute, 2009). Data was screened using Grubb's test for outliers to identify any maize yield that was outside of the normal distribution or two standard deviations (Snedecor and Cochran, 1992). No outliers were found in this study.

RESULTS AND DISCUSSION

All of the variables that were measured were analyzed in SAS using the GLM procedure at an alpha=0.1. Only two variables were found to be significantly affected by the various plant population treatments, these being the cob and grain weight in three rows and the measured plants ha^{-1} (or the measured population). The plant population treatments did not have a significant effect on overall maize yields and this is explained by the variability in the measured populations. The measured populations (or plants ha^{-1}) did have an effect on maize yield. The highest yield (11.57 Mg ha^{-1}) was attained from the 1 seed $basin^{-1}$ and 126 basins $plot^{-1}$ treatment, with a target population of 28,000 plants ha^{-1} (Figure 7). The second highest yield (10.82 Mg ha^{-1}) was attained from the 2 seeds $basin^{-1}$ and 126 basins $plot^{-1}$ treatment, with a target population of 56,000 plants ha^{-1}. The 1 seed $basin^{-1}$ and 70 basins $plot^{-1}$ treatment, with a target population of 15,556 plants ha^{-1}, resulted in the lowest yield of 7.53 Mg ha^{-1}. These treatments were not different because of the variability in the measured treatment populations.

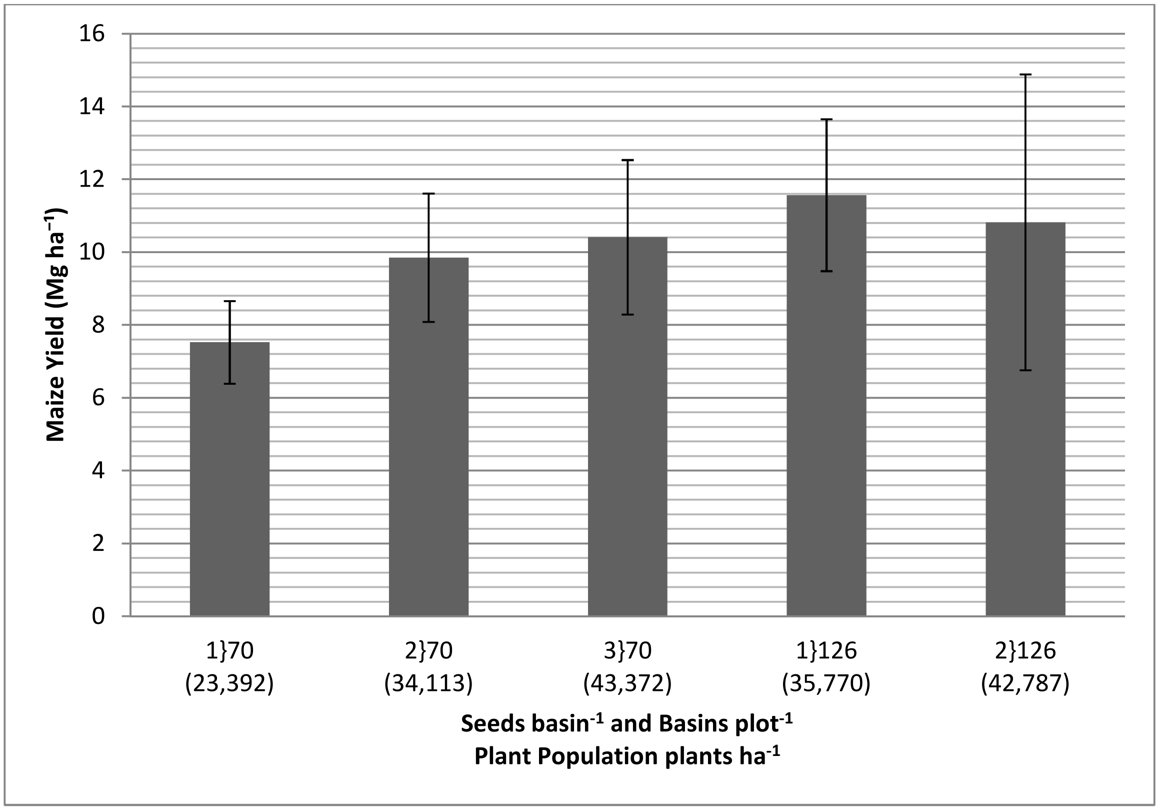

Figure 7. Effect of plant density treatments on maize yield at Maphutseng, Lesotho during the 2010 to 2011 growing season. Plant density treatments did not have a significant effect on maize yield. Error bars are the standard deviations.

Statistical analysis of the measured populations would not differ from that of the target population, as maize yield was calculated on an area basis. These results illustrate that while there was no difference between treatments due to the high variability of the measured populations it may be better to use fewer seeds per basin and to dig more basins per plot to attain higher yields. This is supported by literature stating that competition for light, nutrients, moisture, and other environmental factors between maize plants increases with increasing population (Ali et al., 1999). The result that plant density did not affect maize yields does not agree with Nafziger (1994), or others in the literature (Hunter, 1978; Dwyer et al., 1991; Norwood and Currie, 1996; Norwood, 2001; Muhammad et al., 2010), who found that maize yield is affected by increases in plant populations. Others have reported that plant population may (Hashemi-Dezfouli and Herbert, 1992) or may not (Tethio-Kagho and Gardner, 1988) have a significant effect on maize yield.

In the study done at Maphutseng in Lesotho, Africa, cob and grain weight was affected by the planting population (Table 8). The plant population treatment that resulted in the highest cob and grain weight (32.01 kg three rows^{-1}) was the two seeds basin^{-1} and 126 basins plot^{-1} treatment, with a target population of 56,000 plants ha^{-1}but this treatment was only different from the 1 seed basin^{-1} and 70 basins plot^{-1} treatment (Figure 8). The lowest cob and grain weight (17.93 kg three rows^{-1}) resulted from the one seed basin^{-1} and 70 basins plot^{-1} treatment, target population of 15,556 plants ha^{-1}; which was different from all other treatments except the second plant density treatment (Figure 8).

Table 8. Statistical results for the plant density study conducted at Maphutseng, Lesotho comparing varying plant populations on mean cob and grain weight and mean plants ha^{-1} during the 2010-2011 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Cob and Grain Weight (kg ha^{-1})	Mean Plants ha^{-1}
Plant Density Treatment}			
Target Population (plants ha^{-1})	4	Pr>Value 0.0422	Pr>Value 0.0006
1} 15,556		17.93	23,392
2} 31,111		24.81	34,113
3} 46,667		29.61	43,372
4} 28,000		27.74	35,770
5} 56,000		32	42,787
Replication	3	Pr>F Value 0.0732	Pr>F Value 0.0144

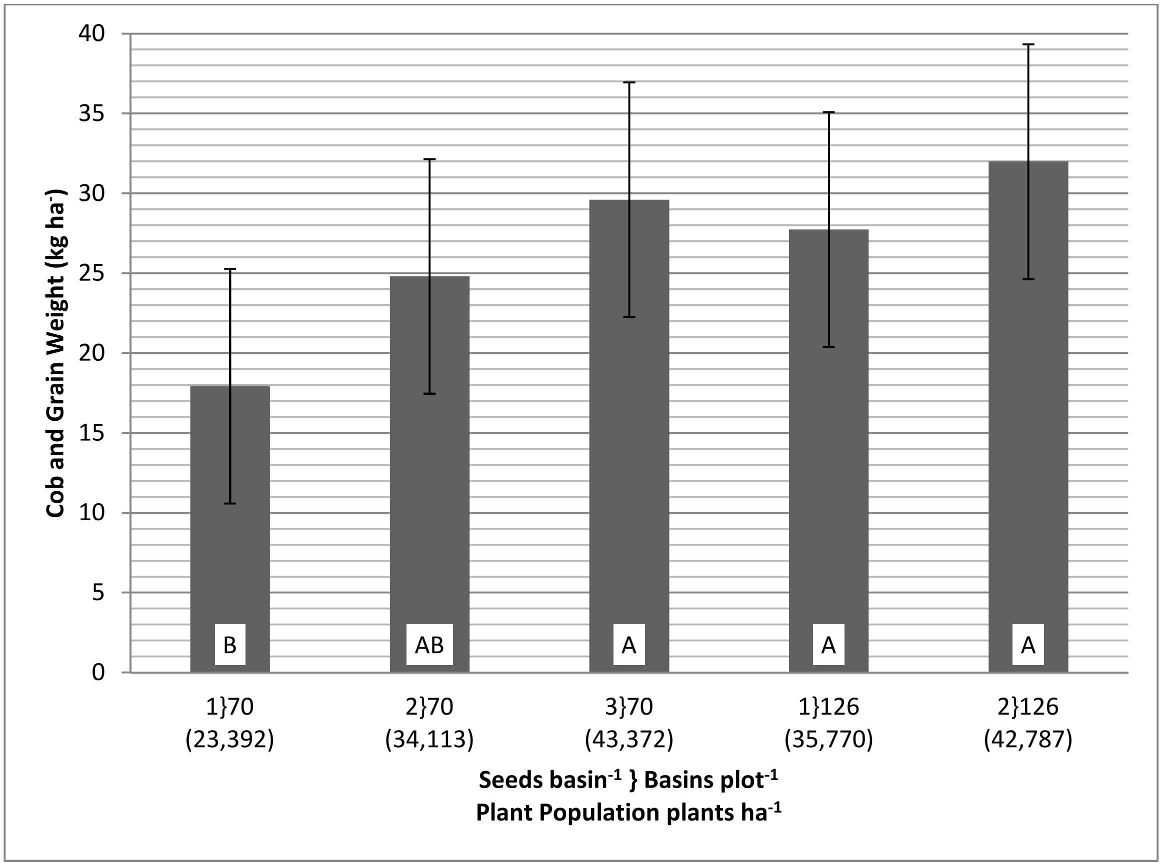

Figure 8. Effect of plant density treatment on cob and grain weight at Maphutseng, Lesotho during the 2010-2011 growing season. Treatments that have the same letter are not statistically different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

Alam et al. (2003) reported that the highest biological yield in maize was achieved at a plant population of 80,000 plants ha^{-1}, which agrees with the findings of this study increasing the plant population increases biological yield. Two studies concluded that an increase in maize plant population resulted in a decrease in the number of kernels row^{-1} (Bavec and Bavec, 2002; Remision and Lucas, 1982). Many researchers have observed a decrease in grains ear^{-1} as the plant population increases (Al-Kaisi and Yin, 2003; Cox, 1996; Gul et al., 2009; Kayode and Agboola; 1981). The result of increasing cob and grain weight with increasing plant population reveals that as the number of seeds placed in each basin increases, maize yield, and cob and grain weight increases in the plots that contained 70 basins. However, the cob and grain weight increased with increasing seeds basin^{-1} in the plots that contained 126 basins; this differs from the maize yield results, which demonstrated by increasing the number of seeds placed in each basin when there are 126 basins plot^{-1} would result in a decrease in maize yield. As the number of seeds placed in each basin increases, the cumulative weight of the cobs produced increases; however, the weight of grain produced is reduced due to competition for light, nutrients, moisture, and other environmental factors (Ali et al., 1999). The results indicate that placing more seeds in a basin and increasing the basins per unit area will result in greater cob and grain weight, but in order to achieve the highest maize grain yield, one would want to use one seed basin^{-1} and 126 basins plot^{-1} to ensure a lower level of competition between maize plants based upon our results.

The plant population for each plot was measured prior to harvesting and this data was statistically analyzed and the results illustrate that the plant population treatments applied did have a significant effect on the number of plants ha^{-1} (Table 8). Table 8 demonstrates that the number of plants ha^{-1} increased with an increase in the number of seeds $basin^{-1}$ and the number of basins $plot^{-1}$, meaning the plant population was controlled relative to each plant population treatment but the target populations were not accurately met.

CONCLUSION

The results from the plant population study show that the plant population treatments did not affect maize yield due to the variability of the measured populations and statistically analyzing the measured populations would not result in an effect on maize yield because the maize yield was calculated on an area basis. The plant population treatments were found to have an effect on the cob and grain weight; cob and grain weight increased with an increase in the number of seeds $basin^{-1}$ for the plots with 70 basins, this trend was also displayed in the plots with 126 basins with the highest cob and grain weight being 32.01 kg three $rows^{-1}$. However, only the one seed $basin^{-1}$ and 70 basins $plot^{-1}$treatment was different from the all other treatments. The differences between maize yield and cob and grain weight can be explained by maize plants competing with each other for nutrients, light, moisture, and other environmental factors. This competition results in fewer grains row^{-1}, fewer grains ear/cob^{-1}, with the cob weight remaining fairly constant. The measured number of plants ha^{-1} was also found to be effected by the plant population treatments. This means that the plant population treatments that were applied did change the plant density of the plots; however, the measured populations were rarely comparable to the target populations, but were not consistently higher or lower (Table 8). This incongruity, coupled with the fact that the replication variable had an effect on the grain weight, cob and grain weight, and the measured plants ha^{-1}, illustrates that the plot size for each treatment would need to be larger in order to account for the variability that was displayed in this study. Plot size may have affected measurements because with the maize being planted on such a large scale by hand, some of the distances between basins within the plots could be inconsistent. Human error could also have been introduced during the plant population density measurements, as the scale of the plots made it possible for sampling errors. While further research is needed to investigate optimum plant population densities for maize using the Likoti method, it is recommended at this point that fewer basins ha^{-1} and more seeds $basin^{-1}$ be used when planting, no matter the target population density because of the effort involved in digging the basins. Overall, due to the lack of replicated scientific studies and the variability of the measured populations, further research is recommended to investigate the interactions of maize plant populations, maize yield, and cob and grain weight. Through future research studies, more specific recommendations may be available for planting density for maize planted in the region of sub-Saharan Africa where the current study took place.

4. FERTILIZER APPLICATION RATES IN A MAIZE CONSERVATION AGRICULTURE SYSTEM

INTRODUCTION

Nitrogen (N), phosphorus (P), and potassium (K) are the nutrients that affect crop yields to the greatest extent; of these three macronutrients, nitrogen has been found to have the greatest effect on increasing maize yields (Loomis and Connor, 1992; Shaahan et al., 1999; Fabrizzi et al., 2005; Nagy, 2008; Muhammad et al., 2010). The mineral uptake of N has been well established in the literature; Kochian (1991) and Di Tomaso (1995) describe the uptake of N as being heavily dependent on the chemical form and as requiring a large amount of energy from the plant. Supplying a sufficient amount of N to maize crops in order to realize higher yields is critical; this is because adequate N increases both the grain protein content and the size of the grains, and also because sufficient N promotes vigorous growth (Muhammad et al., 2010).

Nitrogen is mobile in the environment, and as a result there is an expectation of losses from applied N through volatilization and/or leaching; while these losses are difficult to quantify because of their dependence on field conditions, one accepted estimate comes from Stevenson (1985), who reported a 30-50% loss of applied N. In addition to the variability losses from applied fertilizer, it has been shown that the N needs of a maize crop can differ across a field and between fields (Carr et al., 1991; Wibawa et al., 1993; Kasper et al., 2003; Wittry and Mallarino, 2004). Due to the uncertainties of fertilizer losses and crop demands, it is very difficult to determine a single level of N that is needed to achieve maximum yields. Gehl et al. (2005) reported that two rates of N were sufficient to attain maximum maize yields depending on location; in most instances 125 kg N ha^{-1} was sufficient, but increases in maize yield were noted with increasing rates up to 185 kg N ha^{-1}. Al-Kaisi and Yin (2003) concluded that to obtain optimal maize yields, an application rate of 140 to 250 kg N ha^{-1} was required, while in another study it was found that increasing N rates up to only 120 kg N ha^{-1} significantly increase maize yields (Ma et al., 2005). Other researchers have also established that lower rates of N can still increase maize yields, such as Kayode and Agboola (1981), who found that the amount of N needed to optimize maize yield varied from 50 to 100 kg N ha^{-1}. This agrees with Shapiro and Wortman (2006), who reported that maize yields increased with increasing N application up to 84 kg N ha^{-1}, while no appreciable response in maize yield was identified at higher rates of N application.

Phosphorus is the second most limiting nutrient for maize production in many regions due to low native soil P and the high P fixation by iron and aluminum oxides (Warren, 1992; Mokwunye et al., 1996; Wittry and Mallarino, 2004). In maize cropping systems, P is important for plant growth, root development, and in the translocation of carbohydrates (Rehm and Schmitt, 2002). P is not biologically fixed, therefore P fertilizer applications are required in order to maintain or increase crop productivity (Kwabiah et al., 2003). Positive crop yield response to P fertilizer applications have been established in previous literature (Le Mare, 1959; Boswinkle, 1961; Wittry and Mallarino, 2004). Kang (1978) reported an increase in maize yield from P fertilizer application rates between 8 and 16 kg P ha^{-1}, and Jama et al. (1997) reported similar results with fertilizer application rates of only 10 kg P ha^{-1} significantly affecting maize yields. Other studies have established that P fertilizer application rates of between 20 and 60 kg P ha^{-1} are adequate for reaching maize yields of 3-7 tons hectare (Kang and Osiname, 1979; Hibberd et al., 1990; Kikafunda-Twine, 1990). Youken et al. (1985) reported attaining maximum dry matter from maize with a P fertilizer application rate of 66 kg ha^{-1}, but also noted significant effects on maize dry matter from P fertilizer application rates as low as 22 kg ha^{-1}.

Potassium is considered essential for crop growth and yield increases and is the most abundant cation in plants; this is because water relations, stomatal opening and closing, photosynthesis, and enzyme activation can all be affected by K (Pettigrew, 2008; Fischer and Hsiao, 1968; Talbott and Zeiger, 1996). Extensive studies have shown that the amount of K taken up by the plant during the growing season is dependent on the crop being grown, native soil K levels and K availability, amount of applied K, management practices used, and environmental conditions of the growing season (Eakin, 1972; Mengel and Kirby, 1987; Mullins and Burmester, 1998). Many studies have concluded that increasing the K fertilizer application rate can significantly affect maize yields (Ebelhar and Varsa, 2000; Heckman and Kamprath, 1992; Mallarino et al, 1999; Neilson et al., 1963; Hera, 1972); however, Bruns and Ebelhar (2006) reported no increase in yield from K fertilization, instead they described increases in K concentration in plant tissues resulting from K fertilization (luxury consumption) – these results are at odds with most of the established literature. Heckman and Kamprathe (1992) observed an increase in ear size which contributed to an increase in grain yield from elevated rates of

K fertilization; the authors also noted an increase in the stover dry matter at maturity. Usherwood (1985) states that K may play a role in the quality development of crops and reports that with K fertilization, increases in both the grain protein content and amino acid content are significant. Cheema et al. (1999) reports that K fertilization will generally increase grain yield, and the highest grain yield reported in this study was that of 6.78 t ha^{-1}, which was observed with a K fertilizer rate of 125 kg K ha^{-1}; however, it was also remarked that there was no significant difference in maize yield with K rates ranging from 75 to 150 kg ha^{-1}.

The variability in the response of maize to N and P fertilization and the lack of repeatable scientific studies from this region demonstrates the need to investigate the optimum N, P, and K fertilizer rates for maize production in Lesotho.

MATERIALS AND METHODS

Site Description

The experimental site in Maphutseng, Lesotho, southern Africa, is located at S 30°12’49.8” and E 27°29’41.3” at an elevation of 1455 meters. The soil series name for this site is Phechela series. The soil is classified as a fine, montmorillonitic, mesic, Typic Pelludert. Soil samples were taken and pH determined using 1:1 soil:water ratio (Kalra, 1995), and the buffer pH was determined using the Mehlich Buffer pH method (Mehlich, 1976). All other elemental analyses were determined using Mehlich-1 extractant and analyzed for concentration using ICP (Mehlich, 1953). The soil analyses found the pH to be 6.63 and the buffer pH to be 6.15 (Table 19 in Appendix). The soil was found to contain 107.5 kg P ha^{-1} and 485.7 kg K ha^{-1}. These findings would place this soil in the high and very high classes for P and K respectively; this correlates with a low response to fertilizer applications for both P and K. Prior to this study this field had been in a long term fallow/pasture for approximately 20 years.

The Roma experimental area is located at S 29°27'44.72" and E 27°43'40.54" at an elevation 1690 meters. The soil series name for this site is Sephula series, and is classified as a fine, mixed, mesic, Aeric Albaqualf. No elemental soil analysis was available from that site.

Temperature and precipitation data was attained from the Maseru International Airport, Lesotho. The total amount of precipitation received during the 2010-2011 growing season (October through June) was 97 mm and the average temperature was 15 ^{o}C (NCDC, 2012).

Experimental Design

During the 2009-2010 growing season an experiment was conducted at the Maphutseng, Lesotho research site that evaluated the effect of varying rates of both N and P fertilizer on three different plant population densities and the associated maize yields. This study used three N fertilizer application rates (0, 30, 60 kg N ha^{-1}) and three P fertilizer application rates (0, 50, 100 kg P_2O_5 ha^{-1}), as well as three target population densities of 17,771; 35,554; 53,331 plants ha^{-1}. Each treatment consisted of one combination of the nitrogen and phosphorous fertilizer application rates applied to one of the three populations; the N source was urea and the P source was triple super phosphate (TSP). All treatments were assigned in a completely randomized block design with four replications, three target populations, and nine treatments, giving a total of 108 experimental units (Table 22 in Appendix). All plots within this study received 20 kg K_2O ha^{-1} base dressing on the date of planting, were planted using the Likoti method, a common planting method where a small basin is dug that is approximately the width of the hoe and twice that size in length during the dry season, and the plot size was 6 m by 3 m. Table 9 lists the treatments applied to the three populations.

The following growing season (2010-2011) this study was split into separate experiments in order to simplify the experiment and to distinguish the effect of each macronutrient, N, P, and K on maize yield. These experiments were put into place at both the Maphutseng and Roma, Lesotho experiment sites, and evaluated the effect of varying fertilizer application rates of N, P_2O_5, and K_2O on maize yield separately for each nutrient. Each experiment from both growing seasons was planted with the Pioneer hybrid 31G54 maize using the Likoti method for planting. The planting date for the N, P and plant population study conducted at the Maphutseng, Lesotho site was November 20, 2009 and the study was harvested on July 5, 2010. For the following growing season, the planting dates were November 26, 2010 for the N experiment and November 29, 2010 for the P and K for the experiments conducted at Maphutseng; all three fertilizer application rate experiments were harvested on July 7, 2011. The planting date for the N, P, and K experiments conducted at the Roma, Lesotho site was December 1, 2010; these were harvested on July 7, 2011.

Table 9. Treatments applied to the three populations (17,777; 35,554; 53,331 plants ha^{-1}) for the fertilizer application study conducted at the Maphutseng, Lesotho site during the 2009-2010 growing season.

Treatment	N applied (kg ha^{-1})	P_2O_5 applied (kg ha^{-1})
1	0	0
2	50	0
3	100	0
4	0	30
5	50	30
6	100	30
7	0	60
8	50	60
9	100	60

For the fertilizer application rate experiments conducted during the 2010-2011 growing season, each plot had a target population of 31,111 plants ha^{-1}; this was established in plots measuring 4.5 m by 10 m by planting 2 seeds $basin^{-1}$ in 70 basins $plot^{-1}$, resulting in a row spacing of 90 cm between basins. The 2010-2011 N fertilizer application rate experiments evaluated the effects of five N fertilizer application rates which are as follows: 0, 50, 100, 150, and 200 kg N ha^{-1}. The nitrogen source used was urea. Each treatment consisted of one of the N fertilizer application rates, and all treatments were assigned in a completely randomized block design with four replications and 5 treatments, giving a total of 20 experimental units (Table 23 in Appendix). All plots within the N fertilizer application rate experiment received the same P (P_2O_5) and K (K_2O) fertilizer application on the date of planting. Table 10 lists the treatments, the equivalent grams $basin^{-1}$ of N fertilizer, and the application rates for both the P and K fertilizers.

Table 10. N fertilizer application rate treatments and P and K fertilizer application rates for the N fertilizer application rate experiment conducted at Maphutseng, Lesotho, and Roma, Lesotho during the 2010-2011 growing season.

Treatment	N (kg ha^{-1})	N (g $basin^{-1}$)	K_2O (kg ha^{-1})	K_2O (g $basin^{-1}$)	P_2O_5 (kg ha^{-1})	P_2O_5 (g $basin^{-1}$)
1	0	0	30	4	60	38.6
2	50	7.34	30	4	60	38.6
3	100	14.68	30	4	60	38.6
4	150	22	30	4	60	38.6
5	200	29.34	30	4	60	38.6

The 2010-2011 P fertilizer application rate experiments evaluated five P_2O_5 fertilizer application rates which are as follows: 0, 30, 60, 90, and 120 kg P_2O_5 ha^{-1}. The P source was TSP. Each treatment consisted of one of the P fertilizer application rates, and all treatments were assigned in a completely randomized block design with four replications and five treatments, giving a total of 20 experimental units (Table 24 in Appendix). All plots within the P fertilizer application rate experiment received a base dressing of N and K_2O fertilizer application on the date of planting. Table 11 lists the treatments, the equivalent grams $basin^{-1}$ of P_2O_5 fertilizer, and the application rates for both the N and K_2O fertilizers.

The 2010-2011 K fertilizer application rate experiments evaluated five K fertilizer application rates which are as follows: 0, 20, 40, 60, and 80 kg K_2O ha^{-1}. K fertilizer source was KCl. Each treatment consisted of one of the K fertilizer application rates and all treatments were assigned in a completely randomized block design with four replications and five treatments giving a total of 20 experimental units (Table 25 in Appendix). All plots within the K fertilizer application rate experiment received a P and and N fertilizer application on the date of planting. Table 12 lists the treatments, the equivalent grams $basin^{-1}$ of K fertilizer, and the application rates for both the P and N fertilizers.

Table 11. P_2O_5 fertilizer application rate treatments and N and K fertilizer application rates for the P fertilizer application rate experiment conducted at Maphutseng, Lesotho, and Roma, Lesotho during the 2010-2011 growing season.

Treatment	P_2O_5 (kg ha^{-1})	P_2O_5 (g basin^{-1})	K_2O (kg ha^{-1})	K_2O (g basin^{-1})	N (kg ha^{-1})	N (g basin^{-1})
1	0	0	30	4	150	22
2	30	19.3	30	4	150	22
3	60	38.65	30	4	150	22
4	90	57.9	30	4	150	22
5	120	77.2	30	4	150	22

Table 12. K_2O fertilizer application rate treatments and N and P fertilizer application rates for the K fertilizer application rate experiment conducted at Maphutseng, Lesotho, and Roma, Lesotho during the 2010-2011 growing season.

Treatment	K_2O (kg ha^{-1})	K_2O (g basin^{-1})	N (kg ha^{-1})	N (g basin^{-1})	P_2O_5 (kg ha^{-1})	P_2O_5 (g basin^{-1})
1	0	0	150	22	60	38.6
2	20	2.7	150	22	60	38.6
3	40	5.4	150	22	60	38.6
4	60	8.1	150	22	60	38.6
5	80	10.8	150	22	60	38.6

All plots in all studies during both the 2009-2010 and 2010-2011 growing seasons received an herbicide application both pre-emergence with flumetsulam and S-metolachlor at 1.3 L a.i. ha^{-1} (December 10, 2010 for the Roma, Lesotho site, and December 2, 2009 and December 10, 2010 for the Maphutseng, Lesotho site) and post emergence with glyphosate at 3 L a.i. ha^{-1} (February 1, 2011 for the Roma, Lesotho site, and December 22, 2009 and January 27, 2011 for Maphutseng, Lesotho site). The herbicide treatments were applied using a knapsack sprayer.

Measurements

All plots within all studies were hand harvested. For the N, P, and plant population study conducted at the Maphutseng, Lesotho site during the 2009-2010 growing season, only the grain weight and grain moisture were measured. For the N, P, and K experiments conducted at the Maphutseng, Lesotho site during the 2010-2011 growing season, the grain weight, grain moisture, cob and grain weight, and stover weight were measured. At the Roma, Lesotho site only the grain weight, cob and grain weight, and grain moisture were measured. The grain weight and grain moisture measured from all experiments in this study were used in order to calculate maize dry yield corrected for a moisture content of 15.5% on a mass/mass basis.

Analysis of the Data

Data gathered from the N, P, and plant population experiment conducted at the Maphutseng, Lesotho site during the 2009-2010 growing season were analyzed in SAS using GLM at an alpha=0.1 for main effects from each treatment and interactions between treatments. Data collected from the N, P, and K fertilizer rate experiments from both the Maphutseng and Roma, Lesotho sites during the 2010-2011 growing season were also analyzed in SAS using the GLM procedure at an alpha=0.1 for main effects. Mean separation was performed by Fischer's protected least significant difference (LSD), using an *a priori* method $P<0.1$ (SAS Institute, 2009). Data were screened using Grubb's test for outliers to identify any maize yield that was outside of the normal distribution or two standard deviations (Snedecor and Cochran, 1992). No outliers were found in these studies.

RESULTS AND DISCUSSION

The data analyzed from the N, P, and plant population study from Maphutseng, Lesotho during the 2009-2010 growing season revealed that plant population, N fertilizer treatment, and P fertilizer treatment variables all affected maize yield (Table 13). Interaction effects were found to take place between plant population and replication, plant population and N fertilizer treatment, and replication and N fertilizer treatment. Due to these interactions, the data were split into three groups based on the target plant populations, and then the data were again analyzed for each of the three different plant populations. The data from first plant population, 17,777 plants ha^{-1}, revealed that the replication and N fertilizer treatment variables affected maize yield; an interaction was also identified between replication and P fertilizer treatment that had an effect on maize

Table 13. Statistical analysis for the N, P, and plant population experiment conducted at Maphutseng, Lesotho during 2009-2010 growing season. Pr>F value less than 0.1 is significant.

Level of Plant Population Variable	df	All Three Plant Populations Mean Maize Yield (Mg ha^{-1})	17,777 plants ha^{-1}	35,554 plants ha^{-1}	53,331 plants ha^{-1}
Population	2	Pr>F Value			
		0.024			
17,777 plants ha^{-1}		5.23			
35,554 plants ha^{-1}		5.17			
53,331 plants ha^{-1}		5.88			
N Treatment	2	Pr>F Value	Pr>F Value	Pr>F Value	Pr>F Value
		<0.0001	0.0634	0.0337	<0.0001
0 kg N ha^{-1}		4.46	4.78	4.65	3.97
50 kg N ha^{-1}		5.86	5.86	4.88	6.83
100 kg N ha^{-1}		5.96	5.08	5.97	6.84
P Treatment	2	Pr>F Value	Pr>F Value	Pr>F Value	Pr>F Value
		0.0735	0.4714	0.0584	0.1415
0 kg P_2O_5 ha^{-1}		5.15		4.49	
30 kg P_2O_5 ha^{-1}		5.35		5.29	
60 kg P_2O_5 ha^{-1}		5.79		5.73	
Replication	3	Pr>F Value	Pr>F Value	Pr>F Value	Pr>F Value
		0.3170	0.0908	0.8029	0.0833
Population *Replication	6	Pr>F Value 0.0718			
Replication*N Treatment	6	Pr>F Value 0.0003	Pr>F Value 0.2749	Pr>F Value 0.4363	Pr>F Value 0.031
Replication*P Treatment	6	Pr>F Value 0.0283	Pr>F Value 0.0344	Pr>F Value 0.7617	Pr>F Value 0.7275

yield (Table 13). The maize yield was highest from the 50 kg N ha^{-1} treatment, with an observed dry yield of 5.86 Mg ha^{-1} (Figure 9); the lower yields observed from the 0 and 100 kg N ha^{-1} treatments were not different from each other, but were different than the 50 kg N ha^{-1} treatment. In the second plant population of 35,554 plant ha^{-1}, there was an effect on maize yield from the N treatment and P treatment, but not the replication variable (Table 13). Yield averages for N treatments for the second plant population for all treatments are illustrated in Figure 10. In the third population, 53,331 plants ha^{-1}, both the N treatment and replication variables had an effect on maize yield; additionally, an interaction was identified between these two variables (Table 13 and Figure 11). For the three populations used in this study it was found that there was no maize yield increase above the 50 kg N ha^{-1} treatment that was different from this treatment.

The results of the N treatment experiment conducted at both research locations during the 2010-2011 growing season revealed that N treatment did not have a significant effect on maize yield for the plots at the Maphutseng, Lesotho site (Figure 12) or the plots located at Roma, Lesotho site (Figure 13).

Grain weight, cob and grain weight, grain moisture, and stover weight were measured during harvest for the plots located at the Maphutseng, Lesotho site. N treatment did have an effect on grain moisture (Table 14). The N treatments that resulted in the highest grain moisture % were the 100 and 150 kg N ha^{-1} treatments, with measured average grain moisture of 13.83% and13.88% respectively, which were slightly lower than all other treatments. The lowest grain moisture of 12.94% was attained by the 50 kg N ha^{-1} treatment (Figure 14); which correlates with the statistical results for the

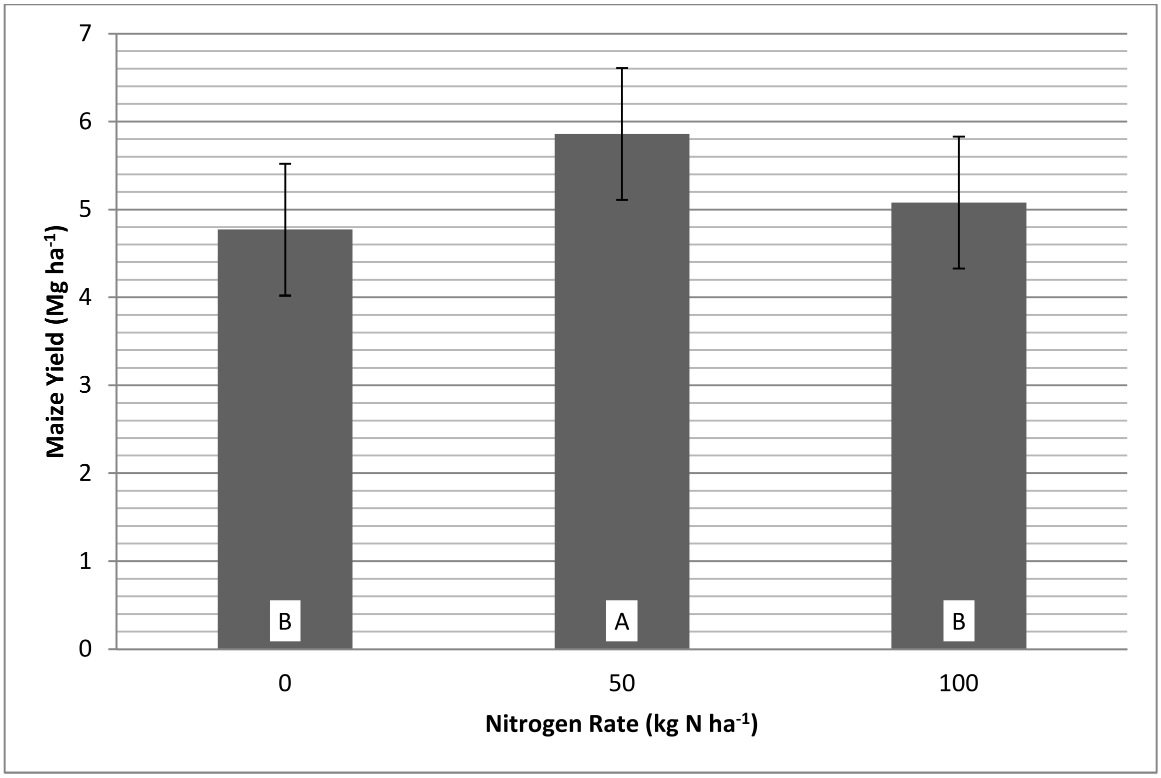

Figure 9. Mean maize yields attained by the N treatments for 17,777 plants ha^{-1} from the N, P, and plant population experiment conducted at Maphutseng, Lesotho during the 2009-2010 growing season. Treatments with the same letter are not significantly different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

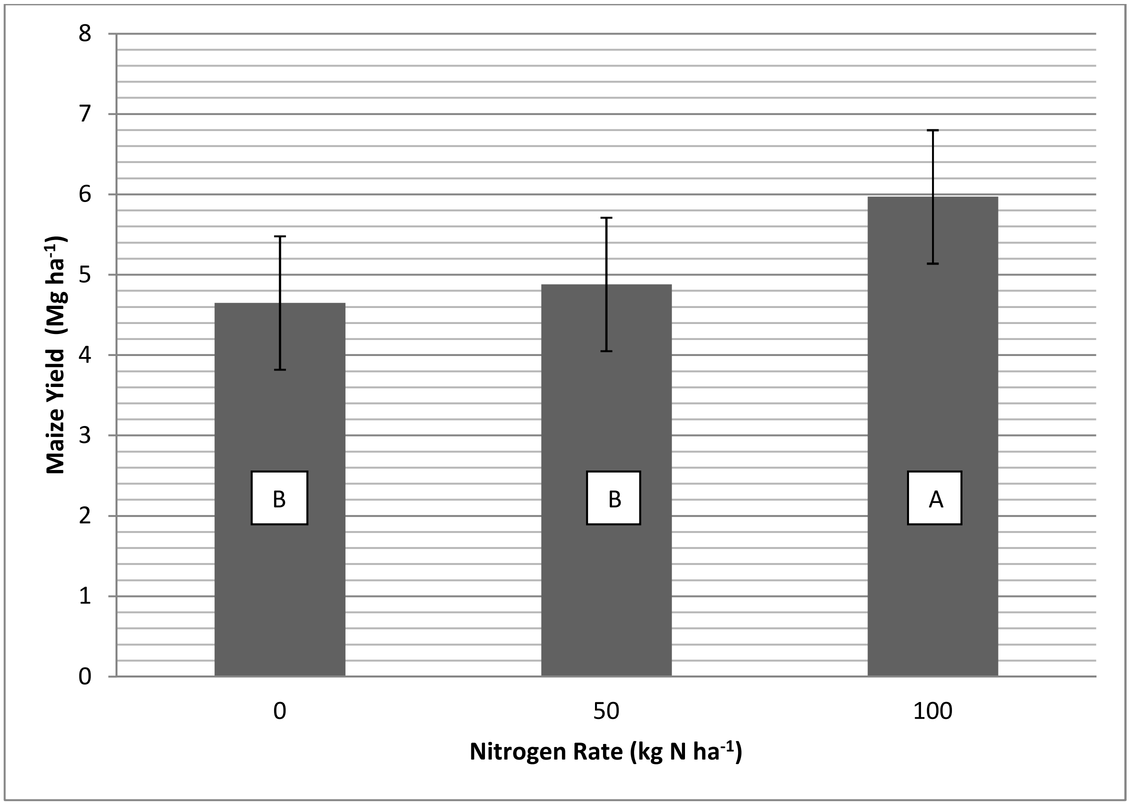

Figure 10. Mean maize yields attained by the N treatments for 35,554 plants ha^{-1} from the N, P, and plant population experiment conducted at Maphutseng, Lesotho during the 2009-2010 growing season. Treatments with the same letter are not significantly different at an alpha=0.1. Error bars are LSD values obtained from statistical analysis.

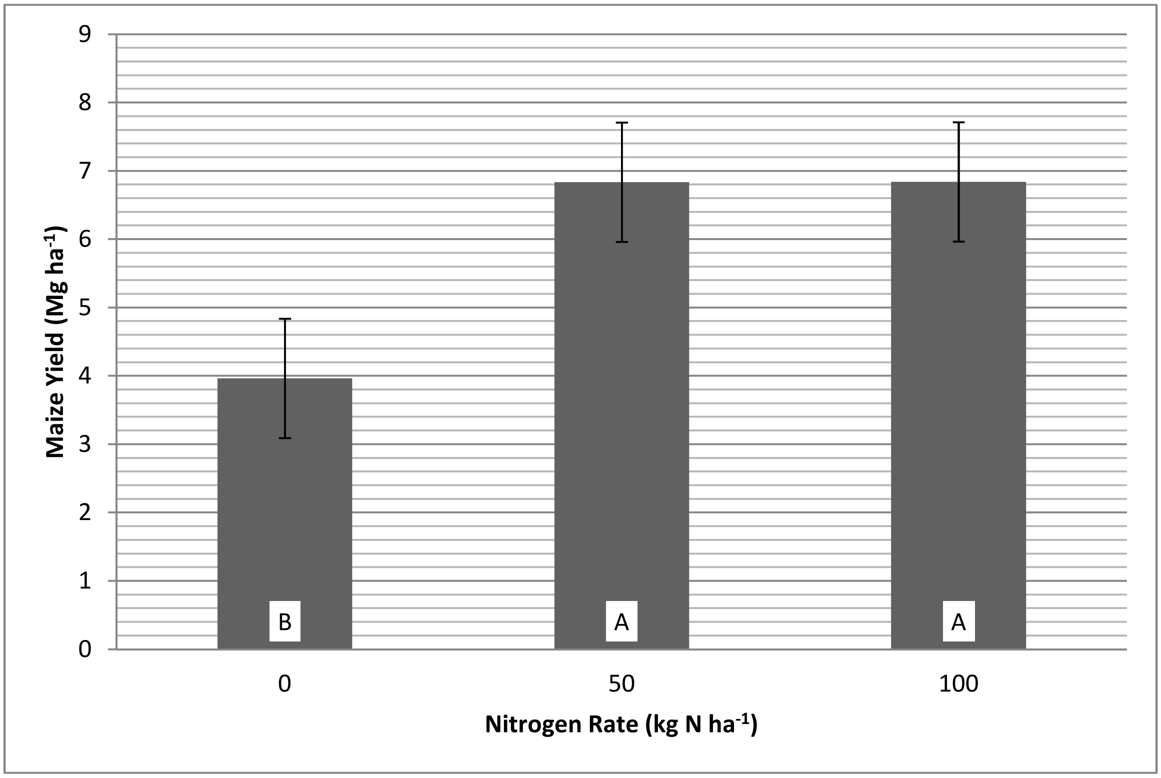

Figure 11. Mean maize yields attained for the N treatments for 53,331 plants ha^{-1} from the N, P, and plant population experiment conducted at Maphutseng during the 2009-2010 growing season. Treatments with the same letter are not significantly different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

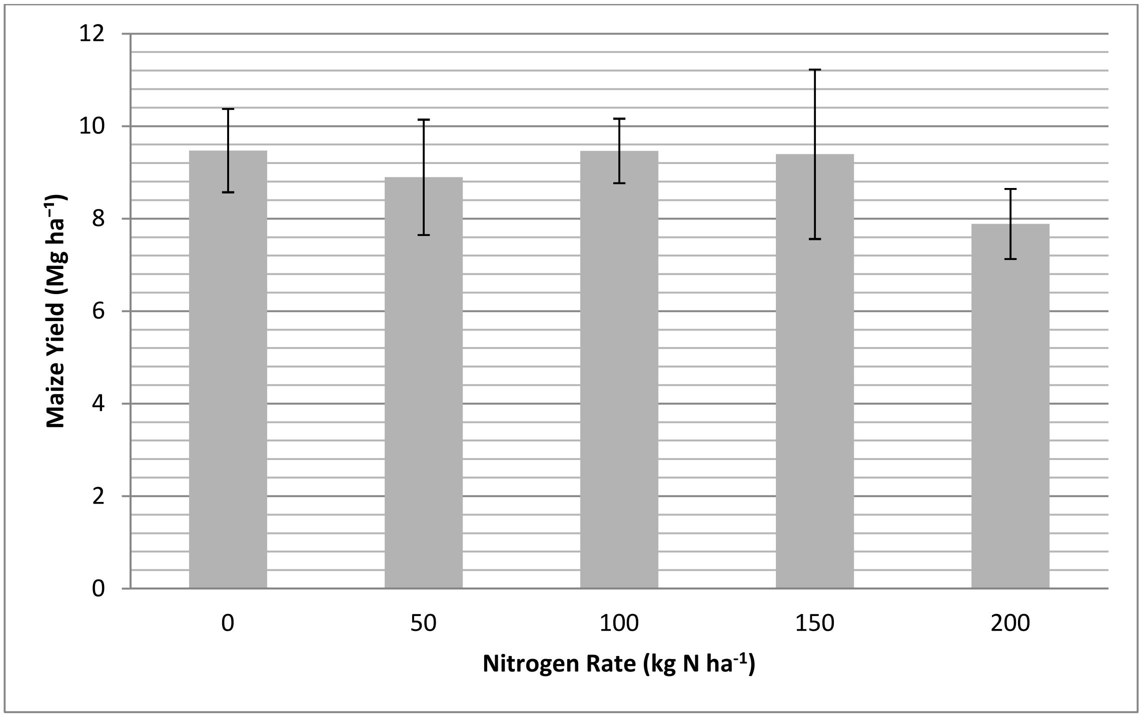

Figure 12. Mean maize yields for the different N fertilizer application rate treatments from the N experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

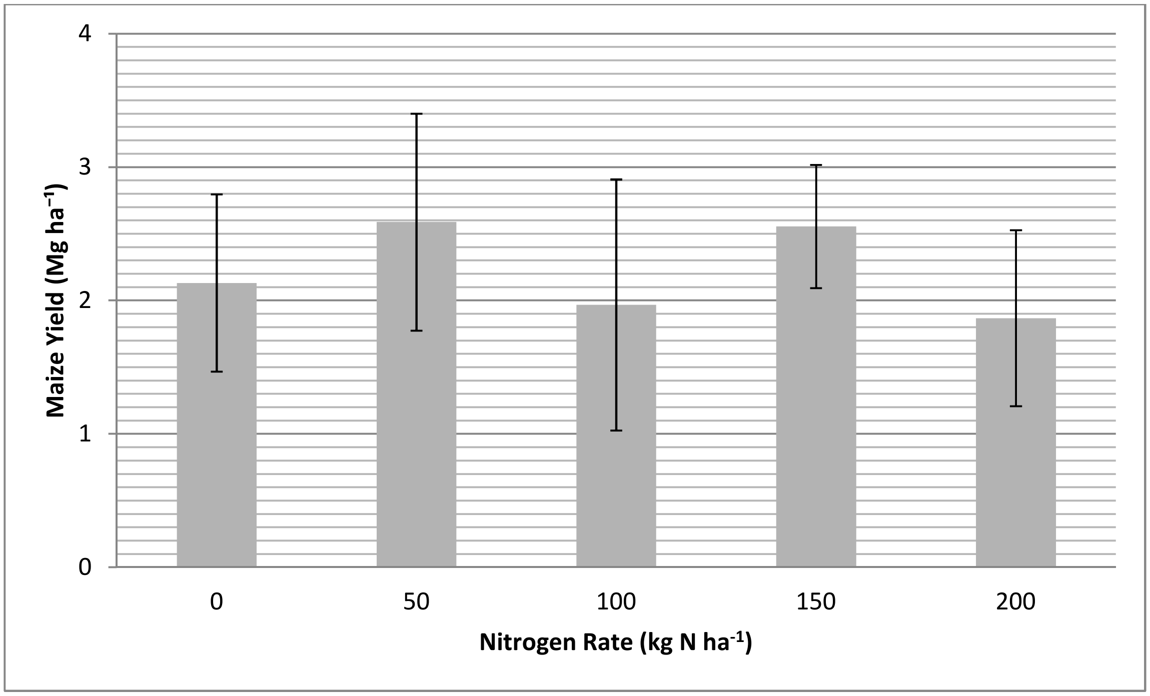

Figure 13. Mean maize yields for the different N fertilizer application rate treatments from the N experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

Table 14. Statistical analysis for the effect of N treatment on grain moisture % and stover weight from the N fertilizer application rate experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Pr>F values less than 0.1 are significant.

Variable	Mean Grain Moisture %	Mean Stover Weight (kg)
N Treatment	Pr>F Value 0.0095	Pr>F Value 0.0208
0 kg N ha^{-1}	13.41	9.61
50 kg N ha^{-1}	12.94	11.21
100 kg N ha^{-1}	13.83	12.53
150 kg N ha^{-1}	13.88	10.53
200 kg N ha^{-1}	13.39	9.76
Replication	Pr>F Value 0.4755	Pr>F Value 0.0149

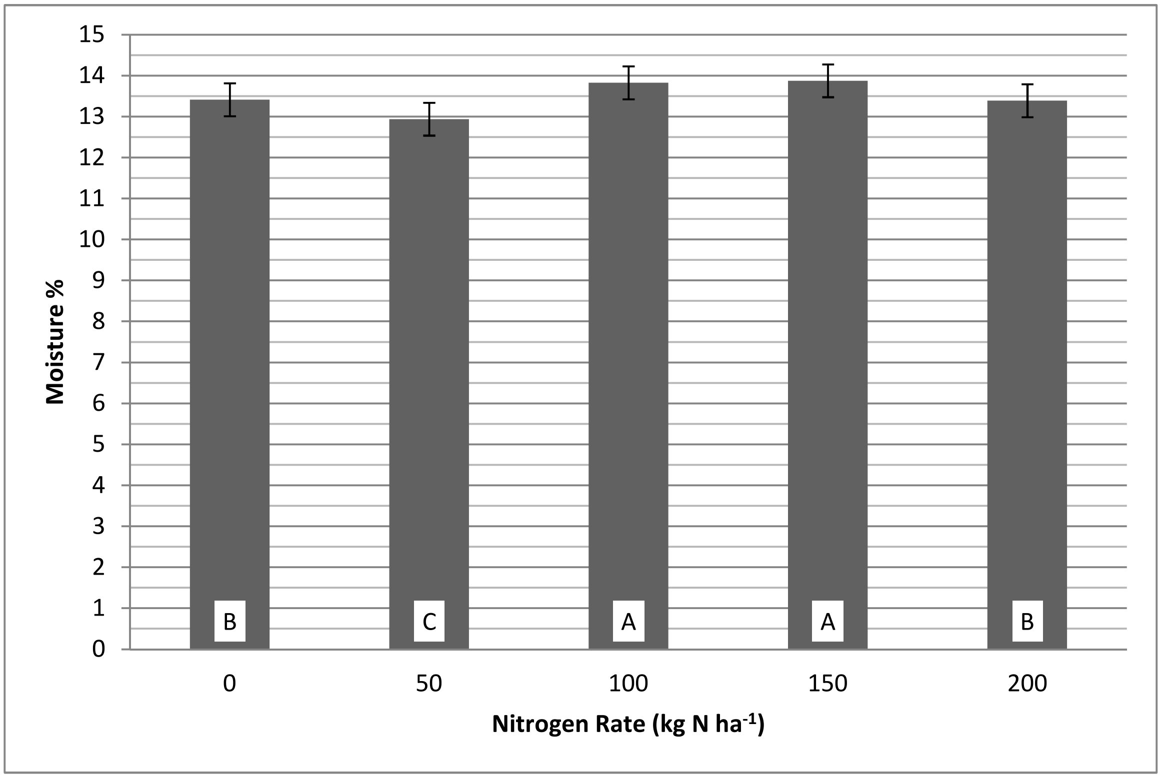

Figure 14. Mean grain moisture % for the different N fertilizer application rate treatments from the N experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not significantly different. Error bars are LSD values attained from the statistical analysis.

maize yield. Effects from the N fertilizer application rate treatments were also observed in the measured stover weight from the plots (Table 14). The highest observed stover weights of 11.52 kg and 12.53 kg were observed from the 50 and 100 kg N ha^{-1} treatments respectively (Figure 15). The treatment that resulted in the lowest stover weight was the 0 kg N ha^{-1}, but the results did not differ from either the 150 or 200 kg N ha^{-1} treatments (Figure 15). Grain weight, cob and grain weight, and grain moisture were measured at harvest for the plots located at the Roma, Lesotho site, however, N treatment was found to have no effect on any of those measured variables.

The results from the N, P, and plant population experiment conducted at the Maphutseng, Lesotho site during the 2009-2010 growing season showed that plant population had an effect on maize yield; this finding is supported by the literature, as Bavec and Bavec (2002) reported that increasing the maize plant population in a range of 90,000 to 130,000 plants ha^{-1} could increase maize yield up to 14.75 t ha^{-1}; this study used much higher plant densities but it illustrates that increases maize density will increase the maize yield. The trend displayed by the N, P, and plant population study of increasing maize yield with increasing N fertilizer is similar to the results of Wopereis et al. (2006), who reported a maize yield response to N fertilizer application rates of both 50 and 100 kg N ha^{-1}. Wopereis et al. (2006) also reported that there was no effect on maize yield from increasing P fertilizer treatments, and concluded that N was the limiting factor for maize yield. Similarly, Szeles et al. (2012) found that there was a maize yield response from increasing N fertilizer up to 150 kg N ha^{-1} with an average yield increase

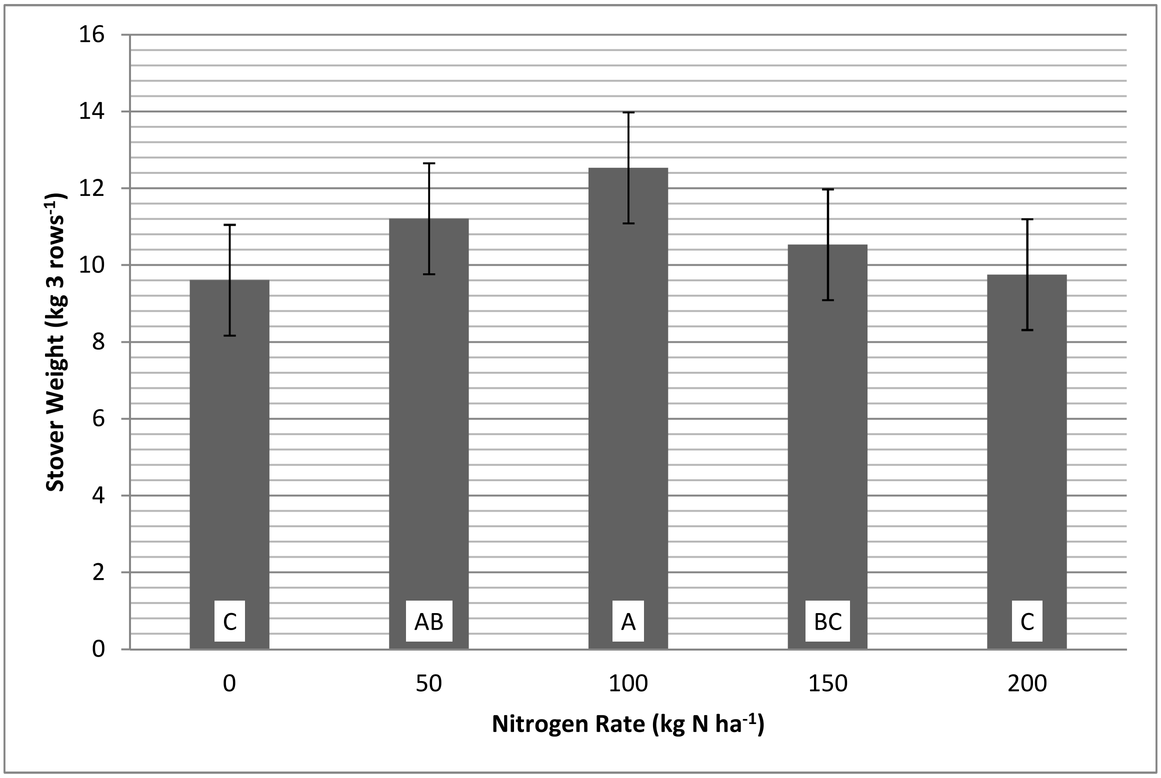

Figure 15. Mean stover weight for the different N fertilizer application rate treatments from the N experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not statistically different at an alpha=0.1.

of 1.34 t ha^{-1}; however, it was also distinguished that the amount of precipitation received heavily influenced the effect of increasing N fertilizer on maize yield, reporting that in a year with adequate precipitation the average yield increase with a fertilizer application rate of 150 kg N ha^{-1} rose to 3.27 t ha^{-1}.

The results from the N treatment experiments that were conducted at both Maphutseng and Roma, Lesotho sites during the 2010-2011 growing season revealed no significant maize yield increase from increasing N fertilizer. Mamo et al. (2003) reported that maize yield did increase with increasing N fertilizer on a whole field basis, but completed a spatial analysis which revealed that the maize yield response to N fertilizer was only observed on half the landscape involved in the study. This result is similar to Lambert et al. (2006), who found that maize yield response to N fertilizer varied spatially and temporally, highlighting the difficulties associated with the management of this input. In this experiment, replication often had a significant effect on maize yield, and the results of Lambert et al. (2006) may help explain why this effect was observed; the plot size in these experiments may not have been large enough to accommodate the spatial variability of the field, such that future studies may actually require a much larger area for each plot in order to ensure that the variability of the field is represented.

Shamudzarira and Robertson (2002) reported that the maize yield response varied temporally depending on precipitation, and observed a trend of increasing maize yield response to increasing precipitation between 250 mm and 450 mm of precipitation; a negative relationship was observed when precipitation totaled more than 450 mm. The potential of maize to respond to N fertilizer inputs is limited by low precipitation because of the limitations to N mobility under low soil moisture conditions; it is also limited by high amounts of precipitation due to the potential of N leaching from the root zone, this can result in the N supply limiting maize yield to a greater extent than water supply alone (Shamudzarira and Robertson, 2002). A similar positive relationship between maize yield and seasonal precipitation ranging from 200 to 500 mm has been documented (McCown et al., 1991). The experimental sites in Lesotho received approximately 560 mm of precipitation during the 2009-2010 growing season (October through June) and 97 mm of precipitation during the 2010-2011 growing season (NCDC, 2012). The lack of maize yield response to N fertilizer may have been the result of too much precipitation during the 2009-2010 growing season; alternately, during the 2010-2011 growing season it may have been due to the lack of precipitation.

The data analyzed for the P treatment experiment that was conducted at the Maphutseng and Roma, Lesotho sites revealed that P treatment did not have an effect on maize yield for the plots located at the Maphutseng, Lesotho site (Figure 16), but did have an effect on maize yield for the plots located at the Roma, Lesotho site (Table 15). The highest yield observed at the Maphutseng, Lesotho site was 10.54 Mg ha^{-1} from the treatment with a P fertilizer application rate of 120 kg P_2O_5 ha^{-1}, and the lowest yield achieved was from the 0 kg P_2O_5 ha^{-1} treatment at 8.67 Mg ha^{-1}. Grain weight, cob and grain weight, grain moisture, and stover weight were all measured at the time of harvest for the plots at Maphutseng, Lesotho, but statistical analysis of the data revealed that P treatment was found to have no effect on those variables. This result could be explained

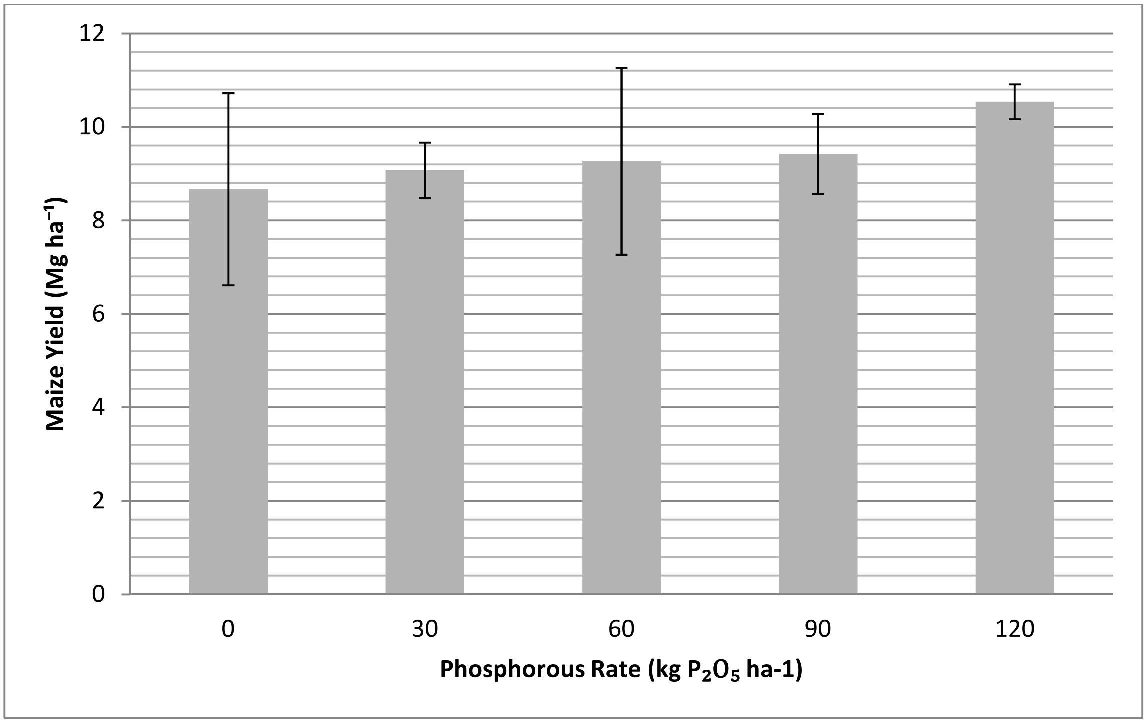

Figure 16. Mean maize yield for the different P_2O_5 fertilizer application rate treatments from the P experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations

Table 15. Statistical analysis for the effect of P_2O_5 fertilizer application rate treatment on maize yield and mean cob and grain weight from the P experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Maize Yield (Mg ha^{-1})	Mean Cob and Grain Weight (kg)
P_2O_5 Treatment	4	Pr>F Value 0.0802	Pr>F Value 0.0699
0 kg P_2O_5 ha^{-1}		1.62	3.81
30 kg P_2O_5 ha^{-1}		2.16	4.68
60 kg P_2O_5 ha^{-1}		0.96	2.25
90 kg P_2O_5 ha^{-1}		0.66	1.49
120 kg P_2O_5 ha^{-1}		1.28	2.91
Replication	3	Pr>F Value 0.1917	Pr>F Value 0.1865

by the high amount of P observed in the soil samples taken from this site (107.5 kg P ha^{-1}), which correlates with a high soil P class resulting in a low response to P fertilizer.

The P fertilizer application rate treatments did have an effect on maize yield for the plots located at the Roma, Lesotho site, but the results deviated strongly from the mean yields for the plots located at the Maphutseng, Lesotho site. At the Roma, Lesotho site, the highest maize yield of 2.16 Mg ha^{-1} was achieved with the 30 kg P_2O_5 ha^{-1} treatment, which was statistically different from all other treatments except the 0 kg P_2O_5 ha^{-1}treatment (Figure 17). Grain weight, cob and grain weight, and grain moisture were measured when the maize was harvested at the Roma, Lesotho experimental site. Cob grain weight was found to be affected by the P treatments (Table 15). The highest cob and grain weight of 4.68 kg was attained from the 30 kg P_2O_5 ha^{-1} fertilizer application rate treatment, which differed from the 60 and 90 kg P_2O_5 ha^{-1} treatments (Figure 18).

The results from the Maphutseng, Lesotho research site concluded that maize yield did not respond to P fertilizer application rate treatments agrees with Wopereis et al. (2006), who reported that increases of P fertilizer of 15 to 30 kg P ha^{-1} did not have an effect on maize yield due to high inherent soil fertility. Spatial and temporal variability of P studies have revealed a large variability of soil test P within fields (Nolin et al., 1996; Wittry and Mallarino, 2004; Lambert et al., 2006) and this may help to support the finding that the P fertilizer application rate treatment did have a significant effect on maize yield. However, the literature is inconclusive, as in other studies P has been shown to be a major limiting factor on maize production (Warren, 1992; Mokwunye et al., 1996). Kwabiah et al. (2003) reported that P fertilizer applications did have a significant

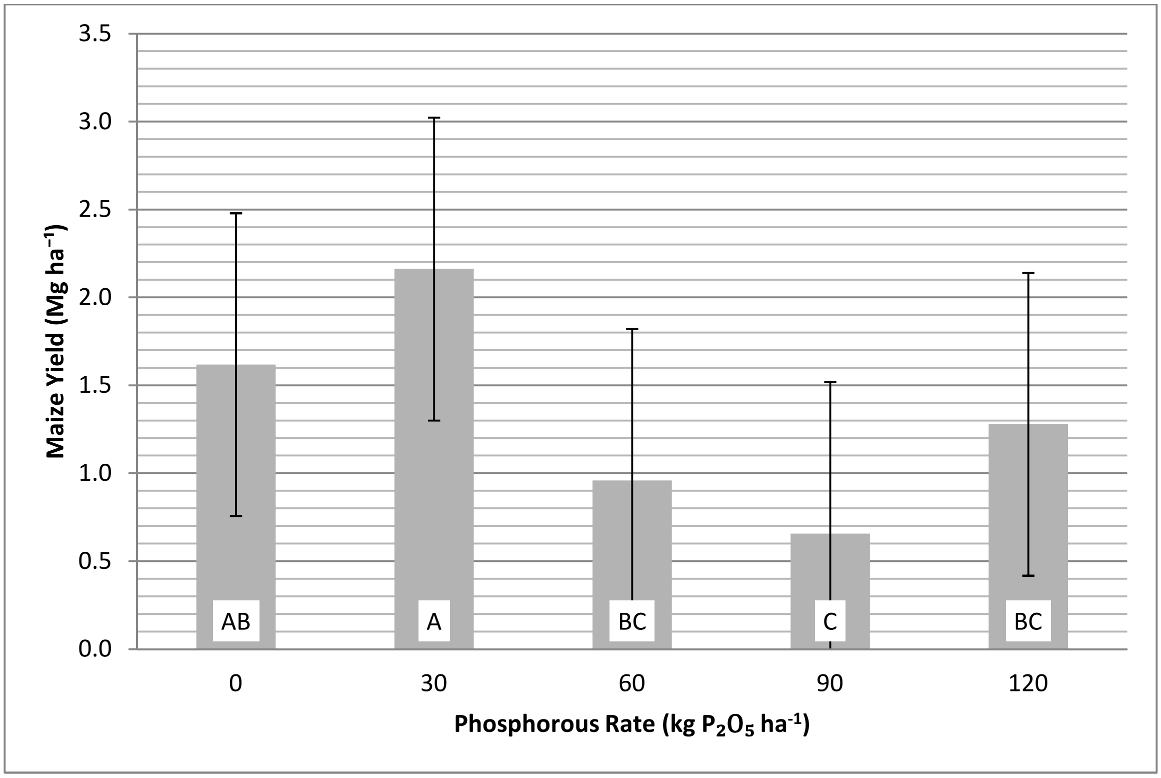

Figure 17. Mean maize yield for the different P_2O_5 fertilizer application rate treatments from the P experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not significantly different. Error bars are LSD values attained from the statistical analysis.

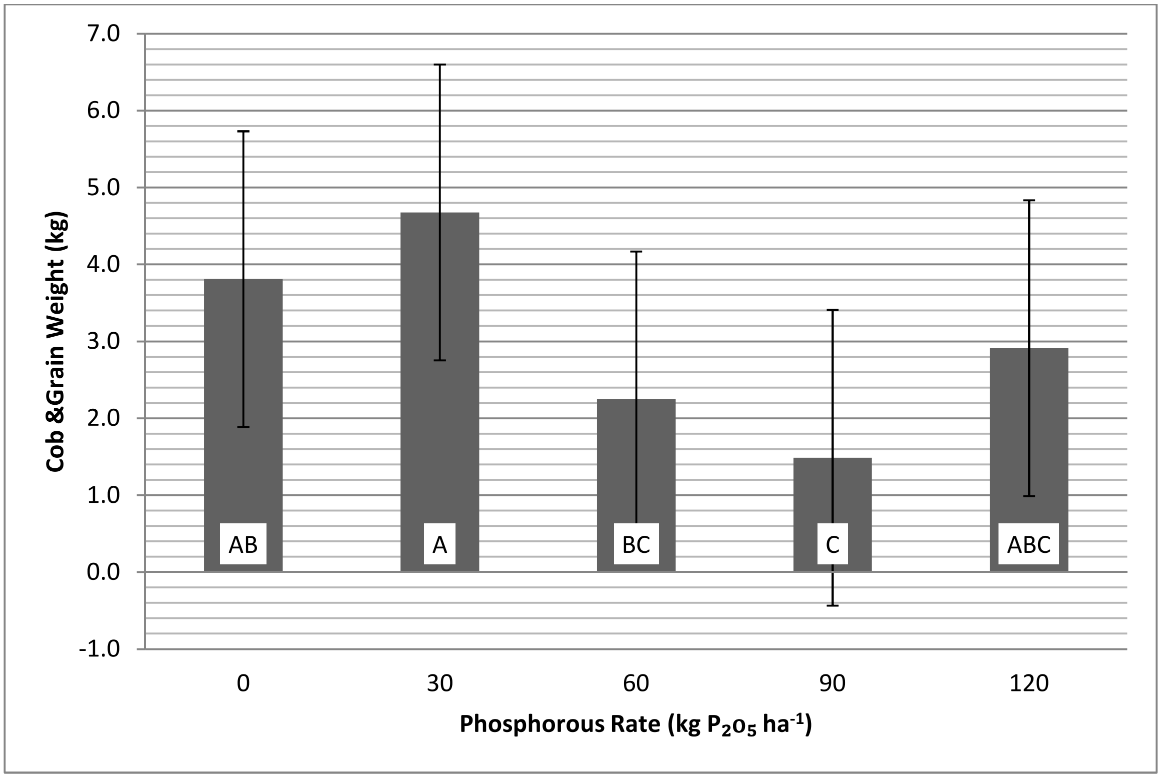

Figure 18. Mean grain and cob weight for different P_2O_5 fertilizer application rate treatments from the P experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not significantly different. Error bars are LSD values attained from the statistical analysis.

effect on maize yield, and observed that the greatest yield of 3.8 t ha^{-1} resulted from a treatment of 150 kg P ha^{-1} fertilizer application. In contrast, Fox and Kang (1978) reported a significant effect of P fertilizer on maize yield, but only at very low rates ranging from 8 to 16 kg P ha^{-1}. Ayub et al. (2002) reported that leaf area per plant, green fodder yield, and dry matter were all significantly affected by P fertilizer application rates ranging from 40 to 80 kg P ha^{-1}. The results from the P_2O_5 fertilizer application rate experiment conducted at the Roma, Lesotho research site displayed a positive response of maize yield, grain weight, cob and grain weight to P fertilizer application rates up to 30 kg P_2O_5 ha^{-1}, which is in agreement with the literature citing the importance of sufficient P fertilizer application.

Statistical analysis of the K experiment conducted at Maphutseng, Lesotho reveals that K treatment had no effect on maize yield (Figure 19). This result could be explained by the high amount of K observed in the soil samples taken from this site (107.5 kg P ha^{-1}) and this correlates with a high soil K class resulting in a low response to K fertilizer.

The statistical analysis of the K experiment conducted at Roma, Lesotho revealed that K_2O fertilizer application rate treatment did have an effect on maize yield, with the highest maize yield of 4.01 Mg ha^{-1} resulting from the 60 kg K_2O ha^{-1} fertilizer application rate treatment (Table 16 and Figure 20), which was greater than all other treatments except the 40 kg K_2O ha^{-1} treatment.

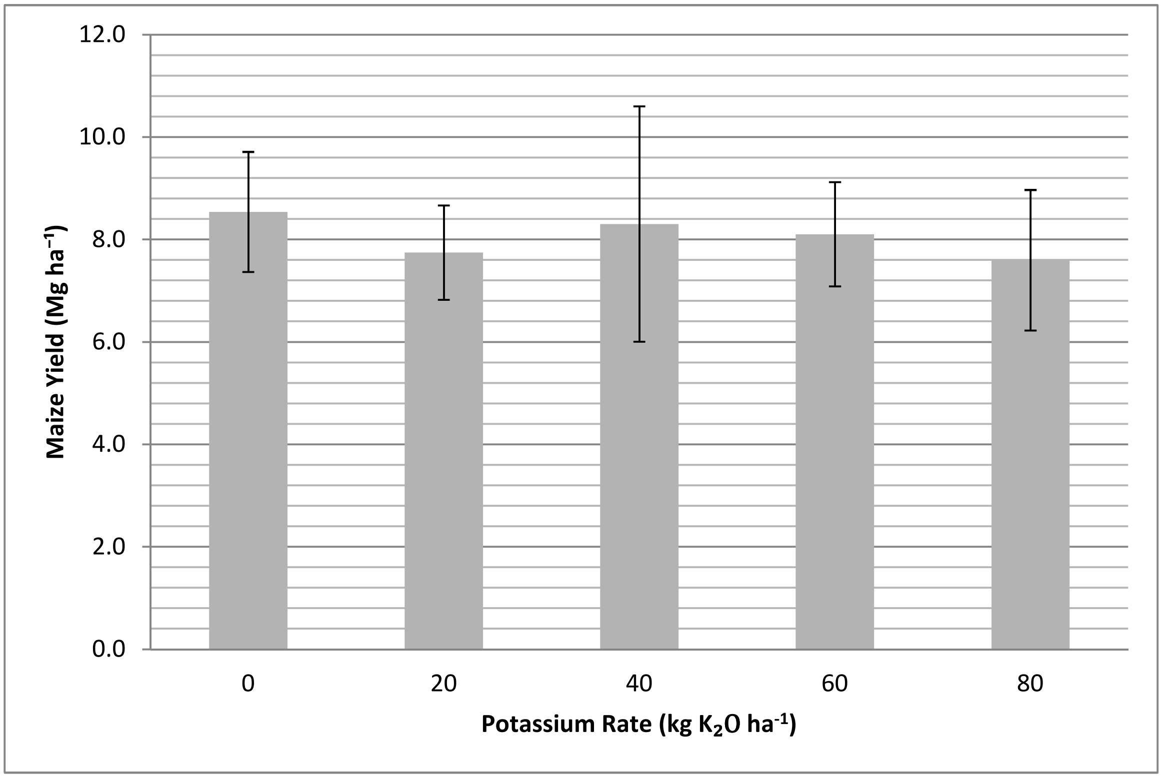

Figure 19. Mean maize yield for the different K_2O fertilizer application rate treatments for the K experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

Table 16. Statistical analysis for the effect of K_2O fertilizer application rate treatment on maize yield and mean cob and grain weight from the K experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Maize Yield (Mg ha^{-1})	Mean Cob and Grain Weight (kg)
K_2O Treatment	4	Pr>F Value 0.0709	Pr>F Value 0.0019
0 kg K_2O ha^{-1}		1.36	2.98
20 kg K_2O ha^{-1}		2.45	5.59
40 kg K_2O ha^{-1}		2.63	6.14
60 kg K_2O ha^{-1}		4.01	9.68
80 kg K_2O ha^{-1}		1.77	6.04
Replication	3	Pr>F Value 0.0579	Pr>F Value 0.0001

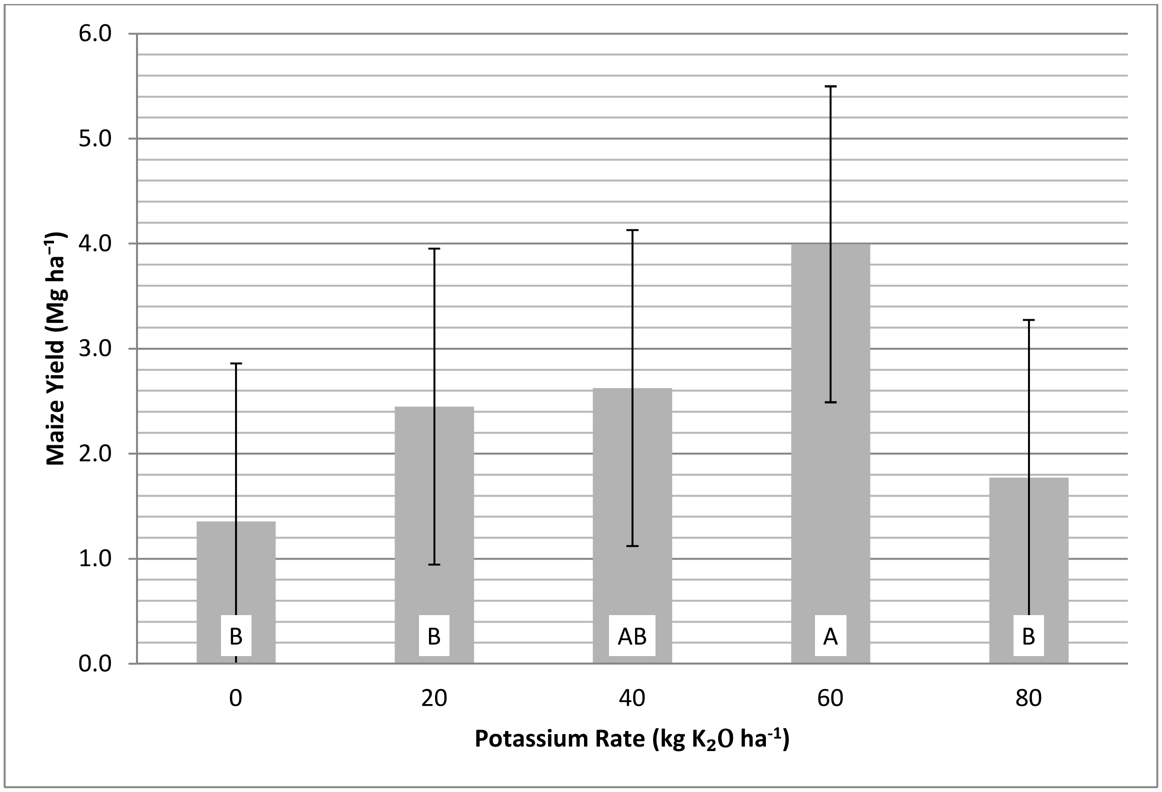

Figure 20. Mean maize yield for the different K_2O fertilizer application rate treatments for the K experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Different letters means the treatments are significantly different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

There was no effect of K treatment on grain weight, cob and grain weight, grain moisture, and stover weight measured at the time of harvest for the plots located at Maphutseng, Lesotho. However, cob and grain weight, and grain moisture were affected by the K treatments measured at the time of harvest for the plots located at Roma, Lesotho. Cob and grain weight was found to be affected by the K treatments (Table 16 and Figure 21); the highest cob and grain weight was also from the 60 kg K_2O ha^{-1} fertilizer application rate treatment, attaining 9.68 kg ha^{-1} (Figure 21), which was greater than all other treatments. The lowest cob and grain weight were found in the 0 and 80 kg K_2O ha^{-1} treatments. The lack of a maize yield response at the Maphutseng, Lesotho site is supported by the findings of Bruns and Ebelhar (2006), who also reported no increase in maize yield with increasing K fertilizer, but instead observed an increase in K within the plant tissues. However, many others have reported an effect on maize yield from K fertilizer (Mallarino et al. 1999; Ebelhar and Varsa, 2000; Welch and Flannery, 1985). Heckman and Kamprath (1992) reported not only an effect on maize yield from K fertilizer, but also observed an effect in the ear size and stover dry weight. Cheema et al. (1999) reported that the number of grains per cob, grain weight, and maize yield were affected by K fertilizer, and that the maximum for each of these was attained with the 125 kg K_2O ha^{-1} rate, but this K fertilizer rate was not different from the 75, 100, or 150 kg K_2O ha^{-1} treatments. The results of the K treatment experiment located at Roma, Lesotho demonstrate that maize yield and cob and grain weight were affected by K treatment, and achieved the maximum values at the 60 kg K_2O ha^{-1}fertilizer application rate.

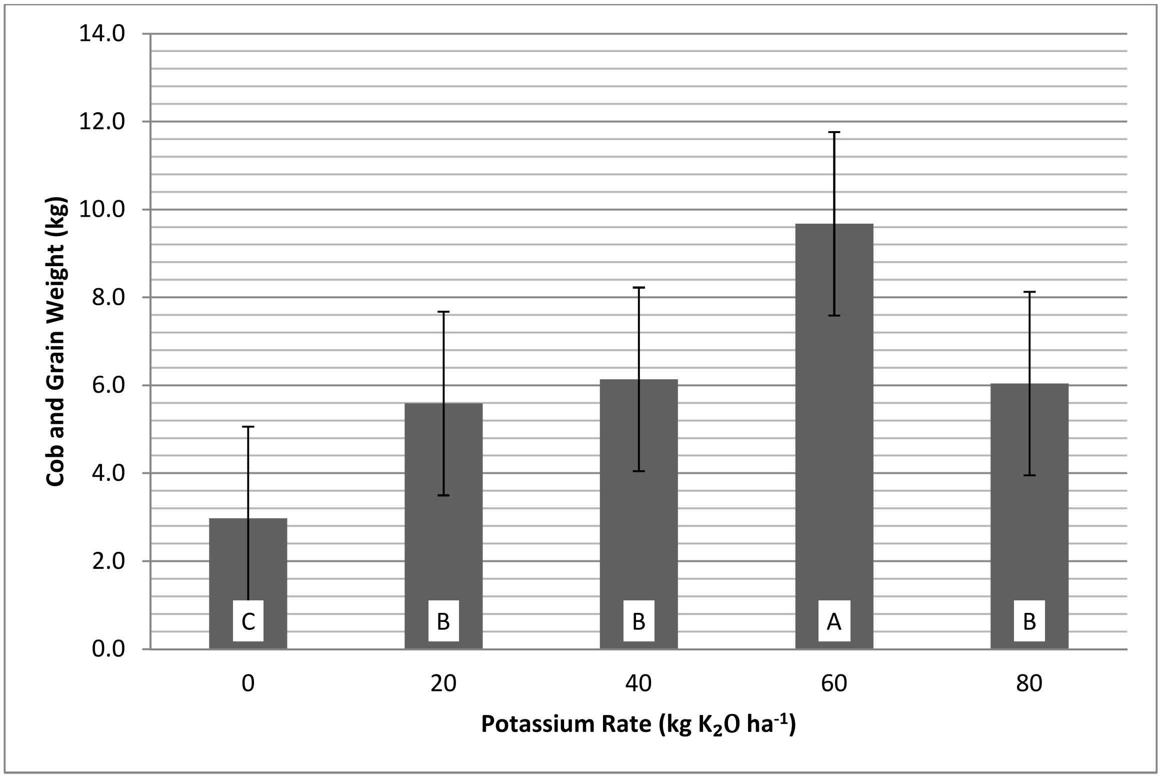

Figure 21. Mean grain and cob weight for the different K_2O fertilizer rate treatments for the K experiment conducted at Roma, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not significantly different at alpha=0.1. Error bars are LSD values attained from the statistical analysis.

The difference between the results from the two experimental sites is mostly likely due to spatially variability in soil test K, as Lambert et al. (2006) found was the case for both N and P. The findings for the Roma, Lesotho site agree with and are supported by the literature.

CONCLUSION

The results from the N, P and plant population density experiment conducted at Maphutseng, Lesotho during the 2009-2010 growing season illustrate that population and N fertilizer rates can affect the maize yield. This experiment illustrated that at a higher plant population there is more need for N and that at those higher plant populations N becomes more limiting than P. This study found that a rate of 50 kg N ha^{-1} resulted in the highest maize yield of 6.83 Mg ha^{-1}. The results from the N fertilizer application rate experiments conducted at Maphutseng and Roma, Lesotho during the 2010-2011 growing season illustrate that N treatment did not have an effect on maize yield at either location, but that it did affect the grain moisture and stover weight only at the Maphutseng, Lesotho site with the highest values for these being attained from 100 (13.83%) and 150 kg N ha^{-1} (13.39%) for the grain moisture and from the 50 (12.53 kg) and 100 kg N ha^{-1} (10.53 kg) for the stover weight. The results from the P treatment experiment conducted at Roma, Lesotho illustrate that P treatment did have an effect on maize yield for the plots located at Roma, Lesotho, with an increasing maize yield response from P treatment up to the 30 kg P_2O_5 ha^{-1}fertilizer application rate with maize yields ranging from 0.66 to 1.62 Mg ha^{-1}; however, there was no such effect observed at the Maphutseng, Lesotho site. Cob and grain weight was found to be affected by P treatment, with a positive response to P fertilizer up to the 30 kg P_2O_5 ha^{-1}attaining the highest cob and grain weight of 4.68 kg. The results from the K treatment experiment conducted at both Maphutseng and Roma, Lesotho during the 2010-2011 growing season illustrate that K treatment had a significant effect on maize yield, but only at the Roma, Lesotho site with yields ranging from 1.36 to 4.01 Mg ha^{-1}. Cob and grain weight was also found to be significantly affected by K treatment for the plots located at Roma, Lesotho. Both variables had a positive response to K fertilizer up to the 60 kg K_2O ha^{-1} fertilizer application rate treatment with the cob and grain weight ranging from 2.98 to 9.68 kg.

The results from all of the experiments evaluating N, P, and K fertilizer application rates demonstrate the variability of the effectiveness of the fertilizers in increasing yield seasonally, and the how the variability of inherent soil fertility may hinder a fertilizer's effect on maize yield. The soils at the Maphutseng site are fertile, in part as a result of long-term fallow soil management, which allowed for accumulation of plant available nutrients and organic matter. The soil analyses conducted on samples taken from Maphutseng, Lesotho revealed that the inherent soil fertility was sufficient for maize production and that the probable response to P and K fertilizers would be low to very low. The high fertility of the soils at Maphutseng is not representative of soils in Lesotho, so it must be emphasized that negative results in fertilizer response in no way preclude the effectiveness of fertilizer use in other parts of the country or sub-Saharan Africa. Differences between the results from each of the two study sites are to be expected because of the disparity between the properties of the soils. The diagnostic albic horizon in the Roma soils indicates that it is highly leached, which could result in more nutrient losses from the Roma site than the Maphutseng site, and account for some of the discrepancy. The Roma soil also has an aquic soil moisture regime, and the soil saturation could negatively influence maize growth. The udic moisture regime of the Phechela series soil is more conducive to maize growth, despite the fact that it also has moderate to poor drainage. The high clay content, inherent fertility, and shrink-swell properties of the Vertisols at the Maphutseng site are likely to decrease the need for fertilizer applications to enhance yields through natural mixing processes; at the Roma site, the high base saturation in the epipedon of the Alfisols should have a positive impact on the fertility of the substrate, while the eluvial processes associated with these soils, evident from the diagnostic albic horizon, likely also have an effect on the maize production because of nutrient leaching.

The need for more soil analyses is apparent, particularly due to the fact that no N analyses were conducted for the Maphutseng, Lesotho and no soil samples were taken from Roma, Lesotho. Soil samples would need to be taken several times throughout the year at varying depths to investigate the temporal and spatial variability in plant available nutrients (N, P, and K). N mobility makes it difficult to analyze soil samples for plant available N; samples could be taken before planting, before fertilizer applications, after emergence, at various stages of plant growth, before harvest, after harvest, and at some point during the winter to investigate the availability of N throughout the year and with enough sampling over time a method may be developed for collecting these samples. Due to the lack of repeatable scientific studies further research is needed in order to begin to make simple fertilizer recommendations for Lesotho, Africa.

5. EFFICACY OF A SUBSAMPLE TO ESTIMATE TOTAL MAIZE YIELD IN A MAIZE CONSERVATION AGRICULTURE SYSTEM

INTRODUCTION

The efficacy of the use of a subsample to estimate the total yield from a plot has not been reported in the literature. Harvesting maize is a time consuming and often a hurried process, and having the option to take a subsample to use for a total maize yield estimate would save time and may make the need to harvest the entire plot unnecessary for this measurement. Often in Lesotho, Africa, the harvest of maize is a communal effort, and the precision needed to make scientific observations is often not given the required amount of attention, which can depend largely on the observer and can be widely varied among large groups of people. Allowing a smaller group of individuals to take relatively small subsamples from each plot may actually result in a more precise measure of the total yield because of the opportunity to spend more time recording data. One variable that is difficult to quantify is the potential for errors to arise during the measurement of the subsample due to observer bias. Due to this fact, and the fact that no literature is readily available on this matter, continued scientific research is warranted. In this study, subsamples were taken from each fertilizer application rate study and the plant population density study that was conducted at the Maphutseng, Lesotho site during the 2010-2011 growing season to evaluate the efficacy of a subsample to estimate maize yield.

MATERIALS AND METHODS

Site Description

The experimental site at Maphutseng, Lesotho, southern Africa is located at S 30°12’49.8” and E 27°29’41.3” at an elevation of 1455 meters. The soil series name for this site is Phechela series. The soil is classified as a fine, montmorillonitic, mesic, Typic Pelludert. Soil samples were taken and pH determined using wet pH method, 1:1 soil:water ratio (Kalra, 1995), and the buffer pH was determined using the Mehlich Buffer pH method (Mehlich, 1976). All other elemental analyses were determined using Mehlich-1 extractant and analyzed for concentration using ICP (Mehlich, 1953). The soil analyses found the pH to be 6.63 and the buffer pH to be 6.15 (Table 19 in Appendix). The soil was found to contain 107.5 kg P ha^{-1} and 485.7 kg K ha^{-1}. These findings would place this soil in the high and very high classes for P and K respectively; this correlates with a low response to fertilizer applications for both P and K. Prior to this study this field had been in a long term fallow/pasture for approximately 20 years.

The Roma experimental area is located at S 29°27’44.72” and E 27°43’40.54” at an elevation 1690 meters. The soil series name for this site is Sephula series, and is classified as a fine, mixed, mesic, Aeric Albaqualf. No elemental soil analysis was completed for the plots at the Roma site.

Temperature and precipitation data was attained from the Maseru International Airport, Lesotho; this data was used due to lack of data collection at the site. The total amount of precipitation received during the 2010-2011 growing season was 97 mm and the average temperature was 15 ^oC.

Experimental Design

The experimental design for the subsample study was the same as the experimental design for the studies from which the subsample was taken. The first study evaluated five planting populations which are as follows: 15,556; 31,111; 28,000; 46,667; and 56,000 plants ha^{-1}. All plots within this study were planted with Pioneer hybrid 31G54 maize and were planted on November 26, 2010. Each treatment consisted of one of the planting populations and all treatments were assigned in a completely randomized block design with four replications of 5 treatments giving a total of 20 experimental units (Table 21 in Appendix). The plot size for this treatment was 10 by 4.5 meters. In order to attain our target populations, the number of basins $plot^{-1}$ and the number of seeds $plot^{-1}$ were calculated based on the area of each plot, and it was found that either 70 basins $plot^{-1}$ or 126 basins $plot^{-1}$ would reach the target populations, depending on the target population and number of seeds $basin^{-1}$. The number of seeds that were placed in each basin ranged from 1 to 3 seeds depending on the target population and number of basins $plot^{-1}$ (Table 6). The row spacing for each 10 by 4.5 meter plot was dependent on the target population. To achieve the higher target plant populations using the Likoti planting system, the interrow spacing was halved, resulting in the higher target populations being planted with 45cm row spacing and 126 basins per plot, while lower target populations had an interrow spacing of 90 centimeters, with 70 basins per plot (Figure 6). The adjustment to row spacing in the higher populations was to accommodate for the plot size, this planting method also resulted in split rows having two fewer basins per plot length. All plots for the plant population study received an herbicide application of glyphosate, which was applied pre-plant at 3 L a.i. $ha^{-1}$and a fertilizer application Table 7 lists the fertilizer rates and the equivalent kg ha^{-1} for N, P, and K fertilizer.

The fertilizer rate experiments were put into place at the Maphutseng, Lesotho experiment site, and evaluated the effect of varying fertilizer application rates of N, P_2O_5, and K_2O on maize yield separately for each nutrient. Each experiment was planted with the Pioneer hybrid 31G54 maize using the Likoti method for planting. The planting dates were November 26, 2010 for the N experiment and November 29, 2010 for the P and K for the experiments conducted at Maphutseng; all three fertilizer application rate experiments were harvested on July 7, 2011.

For the fertilizer application rate experiments conducted during the 2010-2011 growing season, each plot had a target population of 31,111 plants ha^{-1}; this was established in plots measuring 4.5 m by 10 m by planting 2 seeds $basin^{-1}$ in 70 basins $plot^{-1}$, resulting in a row spacing of 90 cm between basins. The 2010-2011 N fertilizer application rate experiments evaluated the effects of five N fertilizer application rates which are as follows: 0, 50, 100, 150, and 200 kg N ha^{-1}. The nitrogen source used was urea. Each treatment consisted of one of the N fertilizer application rates, and all treatments were assigned in a completely randomized block design with four replications and 5 treatments, giving a total of 20 experimental units (Table 23 in Appendix). All plots within the N fertilizer application rate experiment received the same P (P_2O_5) and K

(K_2O) fertilizer application on the date of planting. Table 16 lists the treatments, the equivalent grams basin^{-1} of N fertilizer, and the application rates for both the P and K fertilizers.

The 2010-2011 P fertilizer application rate experiments evaluated five P_2O_5 fertilizer application rates which are as follows: 0, 30, 60, 90, and 120 kg P_2O_5 ha^{-1}. The P source was TSP. Each treatment consisted of one of the P fertilizer application rates, and all treatments were assigned in a completely randomized block design with four replications and five treatments, giving a total of 20 experimental units (Table 24 in Appendix). All plots within the P fertilizer application rate experiment received a base dressing of N and K_2O fertilizer application on the date of planting. Table 17 lists the treatments, the equivalent grams basin^{-1} of P_2O_5 fertilizer, and the application rates for both the N and K_2O fertilizers.

The 2010-2011 K fertilizer application rate experiments evaluated five K fertilizer application rates which are as follows: 0, 20, 40, 60, and 80 kg K_2O ha^{-1}. K fertilizer source was KCl. Each treatment consisted of one of the K fertilizer application rates and all treatments were assigned in a completely randomized block design with four replications and five treatments giving a total of 20 experimental units (Table 25 in Appendix). All plots within the K fertilizer application rate experiment received a P and and N fertilizer application on the date of planting.

Table 17. Statistical results for the effect of population on maize yield for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Pr>F value less than 0.1 is significant.

Variable	df	Mean Maize Yield (Mg ha^{-1})	Mean Number of Cobs ha^{-1}	Mean Grain Weight: cob $plant^{-1}$	Mean Cobs $plant^{-1}$
Plant Density		Pr>F Value	Pr>F Value	Pr>F Value	Pr>F Value
Treatment	4	0.0067	0.0183	0.02	0.0057
Treatment 1		9.31	40,583	0.24	1.75
Treatment 2		12.23	54,350	0.24	1.70
Treatment 3		14.65	65,767	0.23	1.45
Treatment 4		15.73	64,217	0.26	1.58
Treatment 5		15.30	64,367	0.25	1.23
		Pr>F Value	Pr>F Value	Pr>F Value	Pr>F Value
Replication	3	0.0651	0.1094	0.5329	0.042

Table 7 lists the treatments, the equivalent grams basin^{-1} of K fertilizer, and the application rates for both the P and N fertilizers.

All plots in the fertilizer experiments during the 2010-2011 growing seasons received an herbicide application both pre-emergence with flumetsulam and S-metolachlor at 1.3 L a.i. ha^{-1} (December 2, 2009 and December 10, 2010 for the Maphutseng, Lesotho site) and post emergence with glyphosate at 3 L a.i. ha^{-1} (December 22, 2009 and January 27, 2011 for Maphutseng, Lesotho site). The herbicide treatments were applied using a knapsack sprayer.

Measurements

A subsample was taken from the plant density and fertilizer application rate studies at Maphutseng, Lesotho to determine if the use of a subsample to calculate yield can be representative of the yield calculated for the whole plot. For this subsample, ten plants were randomly selected from the center of each plot, were hand harvested, and cob weight, number of cobs plant^{-1}, grain weight and moisture content were measured in order to calculate the maize yield corrected for a moisture content of 15.5% on a mass/mass basis. The number of plants was counted in three 5.55 m lengths of each plot, and the three recorded numbers were averaged: this figure was then used to calculate the population of each plot by using the conversion that 1/1000 of a hectare is approximately 11.11 m^2. The average number of plants in 5.55 m was multiplied by two and then multiplied by 1000 to convert m^2 to hectare; resulting in the measured number of plants ha^{-1}. The maize yield can then be calculated by taking the measured grain weight, again averaged across the three 5.55 m^2, dividing it by the ten plants that were measured and multiplying it by the measured population. Converting the resulting number to yield expressed in Mg ha^{-1} is accomplished by dividing by 1000.

Analysis of the Data

The General Linear Models procedure (GLM) was used to analyze the data for main effects and interactions. Means were separated using Fischer's protected least significant difference (LSD), using an *a priori* method $P<0.1$ (SAS Institute, 2009). Data were screened using Grubb's test for outliers to identify any maize yield that was outside of the normal distribution or two standard deviations (Snedecor and Cochran, 1992). No outliers were found.

Results and Discussion

The subsample data from the plant population experiment revealed that the plant population did have an effect on maize yield. The greatest maize yield was attained by the 1 seed $basin^{-1}$ and 126 basins $plot^{-1}$ treatment which resulted in a maize yield of 15.73 Mg ha^{-1} (Table 17 and Figure 22); which was greater than the one and two seeds $basin^{-1}$ with 70 basins $plot^{-1}$. Further increasing the seeds $basin^{-1}$ does not serve to increase maize yield; this result is very similar to what was observed in the whole plot statistical analysis. The cobs ha^{-1} was also affected by plant population and the highest number of cobs resulted from the 3 seeds $basin^{-1}$, 70 basins $plot^{-1}$ (Table 17).

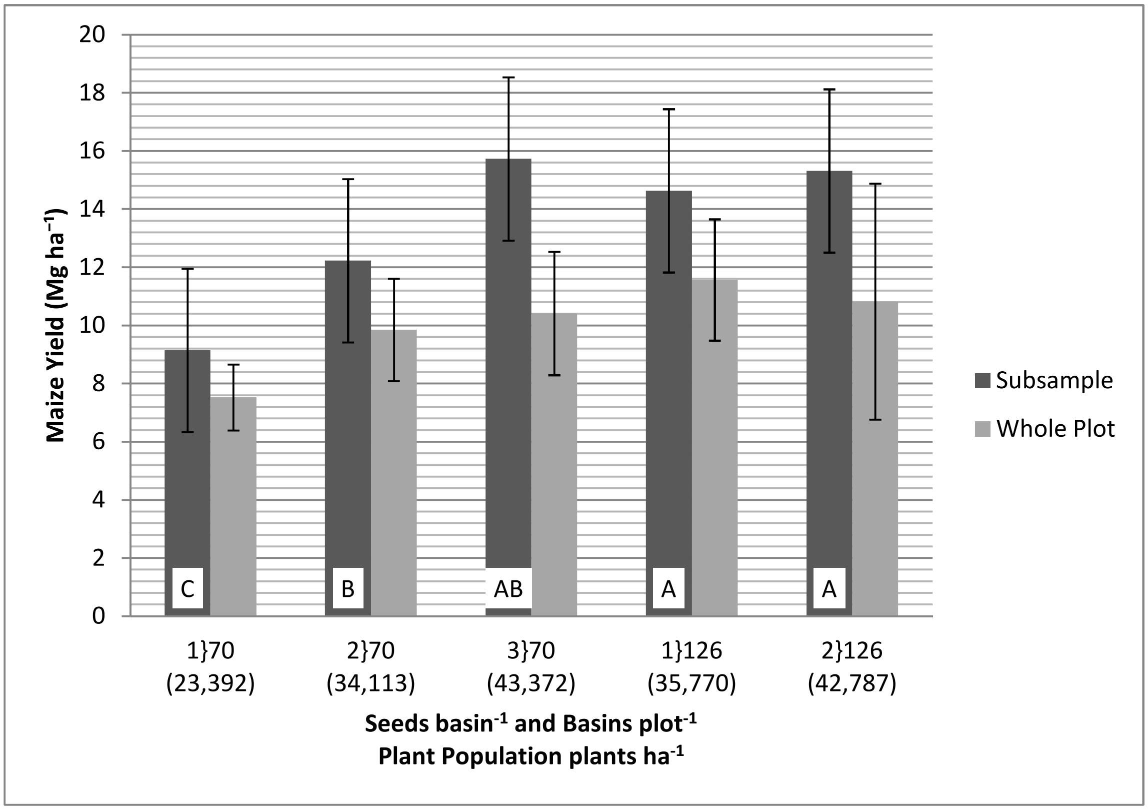

Figure 22. Mean maize yields for the plant population treatments for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. For the subsample, treatments with the same letter are not statistically different at an alpha=0.1, and error bars are LSD values attained from statistical analysis. For the whole plot, error bars are the standard deviations.

However, there were no differences between the 1 and 2 seeds basin^{-1} and 126 basins plot^{-1} or the 2 seeds basin^{-1}and 70 basins plot^{-1} treatments when compared to the 3 seeds basin^{-1} and 70 basins plot^{-1} treatment (Figure 23). The ratio of grain weight to the number of cobs was found to be affected by the plant density (Table 17). The highest ratio, or the most grain on the cob, was determined to be a result of the 1 seed basin^{-1} and 126 basins plot^{-1} treatment, there was no statistical difference between the two treatments that contained 126 basins plot^{-1} (Figure 24). The plant population was also found to affect the number of cobs plant^{-1} (Table 17). The highest number of cobs plant^{-1} was a result of 1 seeds basin^{-1} and 70 basins plot^{-1} treatment, with a mean of 1.75 cobs plant^{-1}; however, the 2 seeds basin^{-1}and 70 basins plot^{-1} and the one seed basin^{-1} and 126 basins plot^{-1} plant density treatments were not different. Fewer plants on an area basis resulted in larger cob sizes, probably as a result of lower competition for moisture and nutrients. Larger cob size with fewer cobs plant^{-1} is preferable, because when there are 2 cobs plant^{-1} it generally results in one good cob and one inferior cob. This suggests that the ideal plant population density would be the one where the lowest number of cobs plant^{-1}, preferably only one, is observed. In the case of this study, the higher plant population densities (above 35,000 plants ha^{-1}) resulted in fewer cobs plant^{-1} (Figure 25). This trend was supported, with the exception of the 3 seeds basin^{-1} and 70 basins plot^{-1} treatment, by higher grain weight to cob# ratios in the plots with higher plant population densities (Figure 24). Overall, the results of the subsample from the plant population experiment suggested the same conclusions as the whole plot analysis when the data were statistically analyzed which suggests this method may merit further research to validate

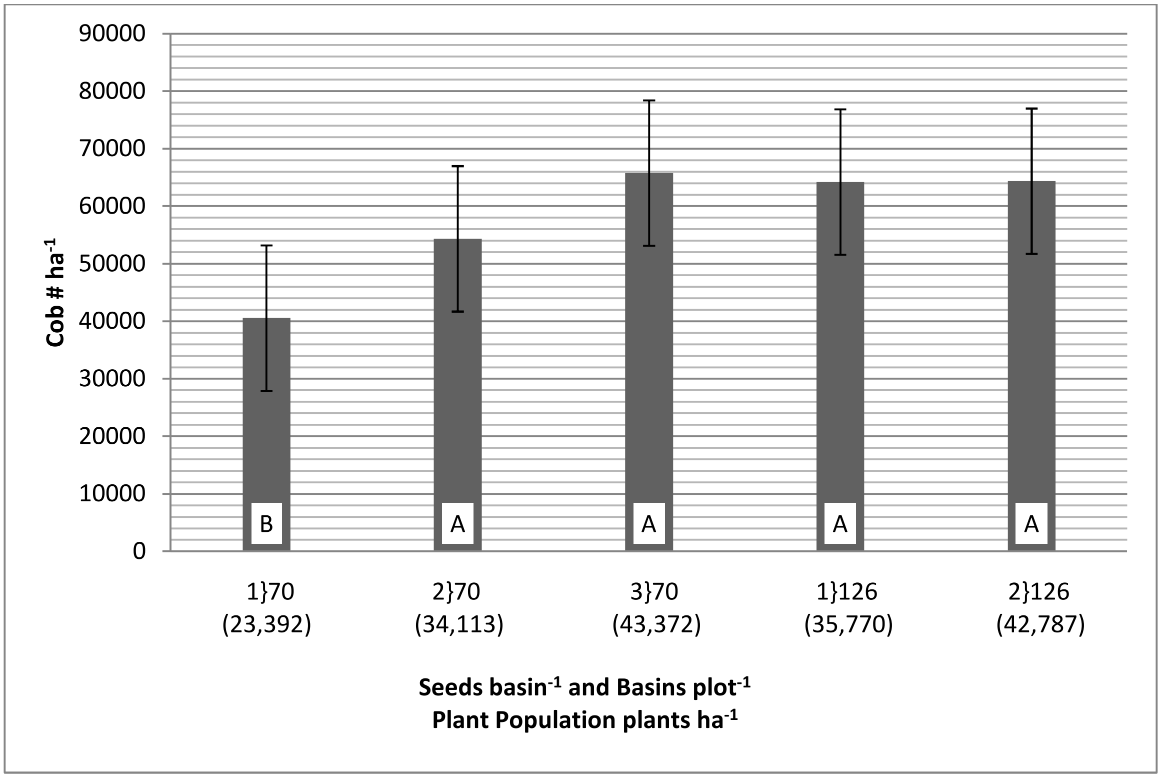

Figure 23. Mean number of cobs ha^{-1} for the plant population treatments for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Treatments that have the same letters are not statistically different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

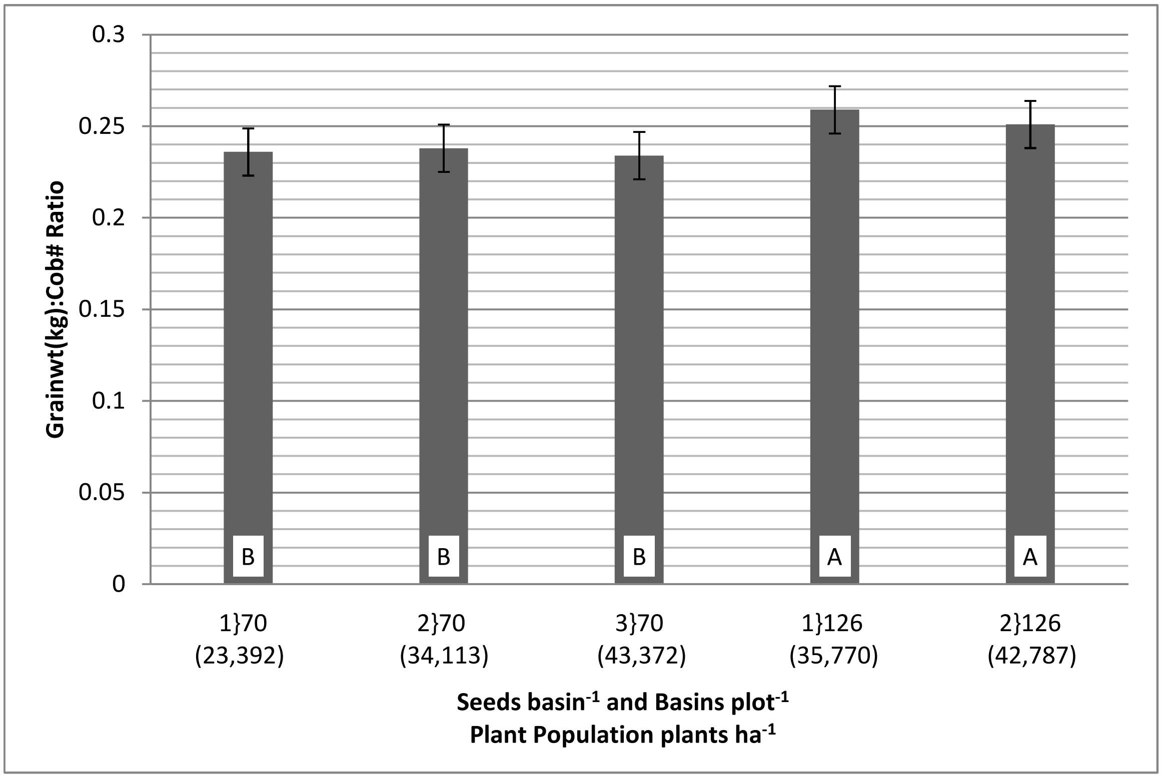

Figure 24. Mean ratio of the grain weight and cobs plant^{-1} for the plant population treatments for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Treatments that have the same letter are not statistically different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

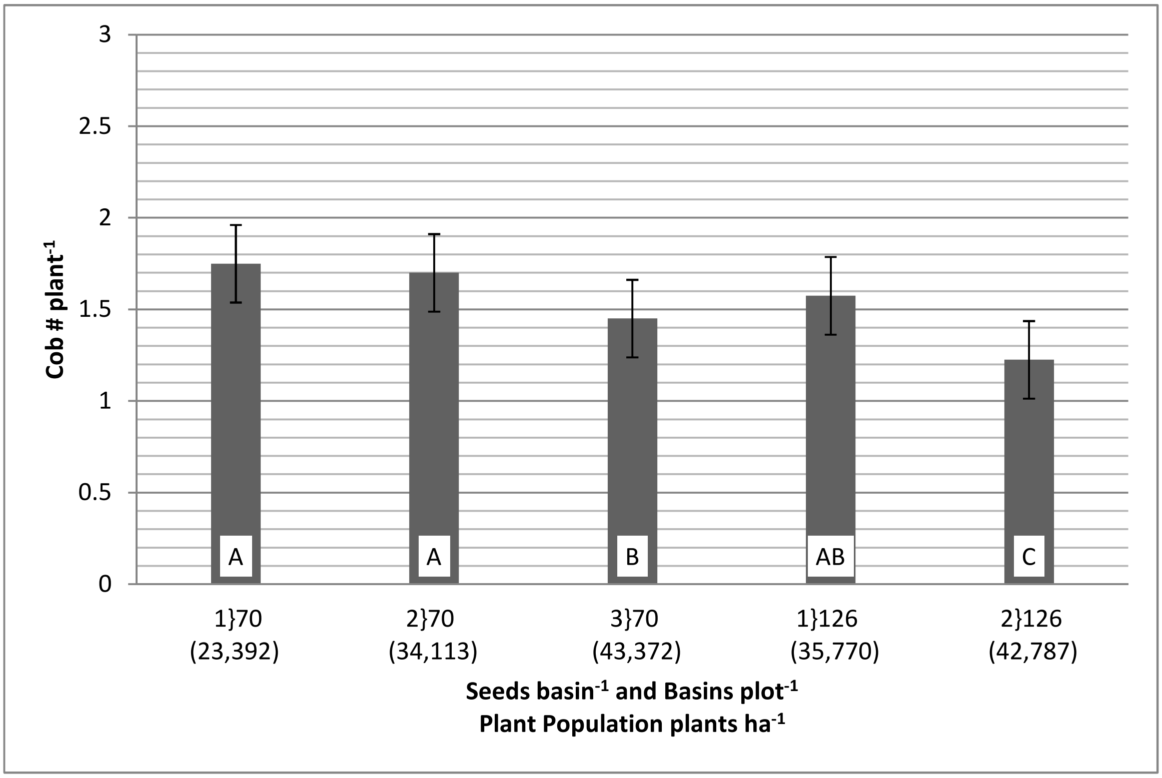

Figure 25. Mean of the cobs plant^{-1} for the plant population treatments for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Treatments that have the same letters are not statistically different at an alpha=0.1. Error bars are LSD values attained from the statistical analysis.

the results. However, the subsample did overestimate the yield by approximately 33% which is a result that again suggests further research is needed to develop better methods and to investigate how much sampler bias affects the statistical analysis and the estimate of the yield.

The subsample data taken from the N treatment experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season revealed that N treatment did not affect maize yield (Figure 26 and Table 18). The N treatment was found to have an effect on the ratio of grain weight to the cobs plant^{-1}; in other words, there was more grain produced on each cob and fewer cobs plant^{-1} as the N fertilizer application rate increased (Table 18). Figure 27 illustrates the increasing grain production up to the 150 kg N ha^{-1} treatment, which was statistically different from all other treatments except the 200 kg N ha^{-1}. This result is comparable to the statistical analysis of the whole plot for the N treatment experiment at Maphutseng, Lesotho, excepting the fact that the positive relationship between grain production and N treatments observed in the subsample was not seen in the whole plot. The whole plot only had an effect on the stover weight which reached its maximum at the 100 kg N ha^{-1} treatment but was not statistically different from the 50 kg N ha^{-1} treatment. The subsample also overestimated the maize yield by an average of approximately 27%, with no pattern by treatments and a range of 15 to 45%. These results also suggest further research is required in order to refine the methods to reduce the effect of sampler bias and to more accurately estimate the maize yield.

The subsample data taken from the P experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season exhibited the same results as the whole

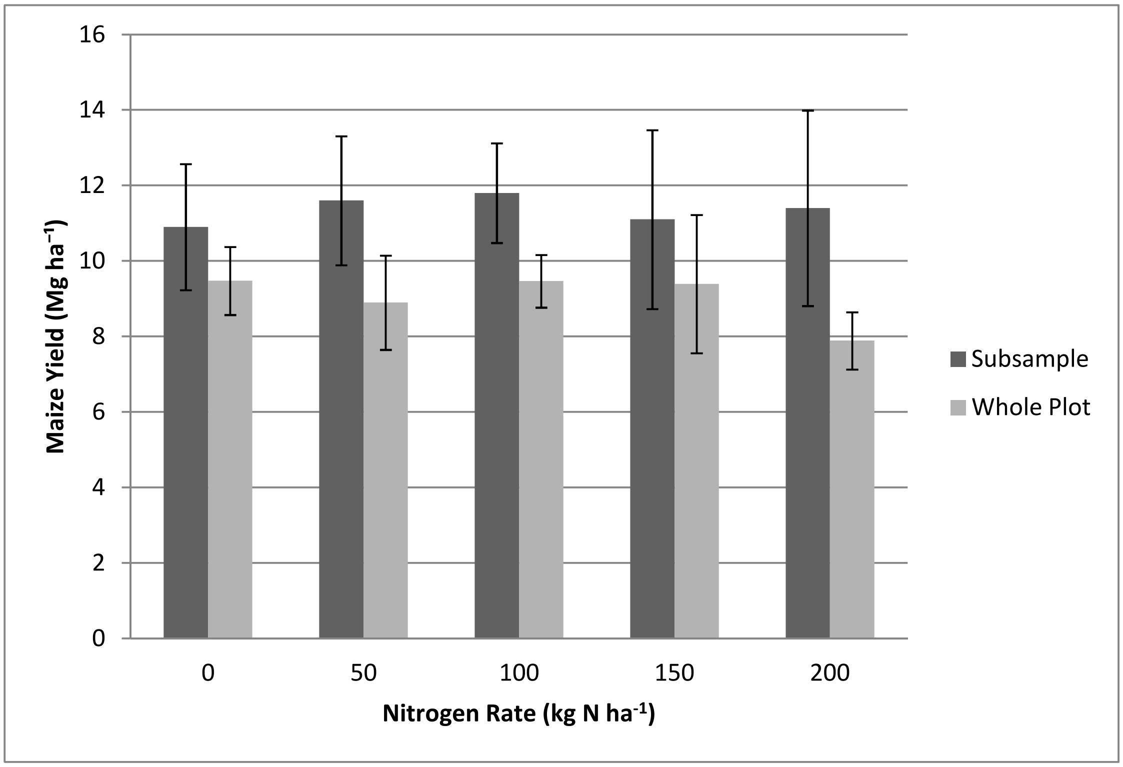

Figure 26. Mean maize yields for the N treatments for the subsample and whole plot analyses taken from Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

Table 18. Statistical results for the effect of N treatment on the ratio of grain weight to cobs plant^{-1} for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Pr>F value of less than 0.1 is significant.

Variable	df	Mean Grain Weight: Cobs plant^{-1}
N Treatment	4	Pr>F Value 0.0039
0 kg N ha^{-1}		0.22
50 kg N ha^{-1}		0.22
100 kg N ha^{-1}		0.24
150 kg N ha^{-1}		0.27
200 kg N ha^{-1}		0.26
Replication	3	Pr>F Value 0.8741

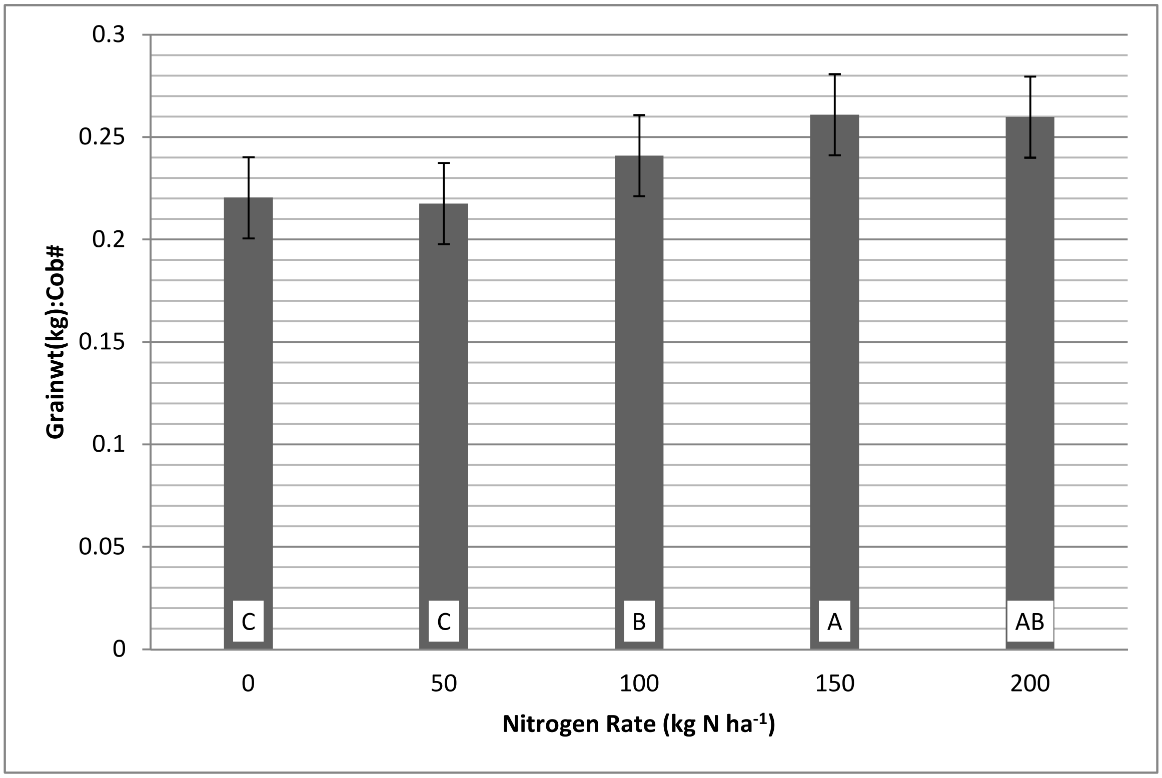

Figure 27. Mean ratio of the grain weight to the cobs plant^{-1} for the N treatments for the subsample taken from Maphutseng, Lesotho during the 2010-2011 growing season. Treatments with the same letter are not significantly different. Error bars are LSD values attained from the statistical analysis.

plot statistical analysis for the maize yield (Figure 28) and none of the other variables measured were affected by P fertilizer treatment. The greatest yields resulted from the highest P fertilizer application rate treatment in both the subsample and the whole plot; however, the subsample overestimated the maize yield by an average of approximately 19%, with overestimation ranging between 7 and 30% for the treatments.

The K treatment experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season did not display any trends in the whole plot nor did the statistical analysis find an effect of the K treatments on maize yield. The same can be said about the subsample which was taken from the K experiment conducted at Maphutseng, Lesotho during the 2010-2011 growing season. The highest yield that was attained was 11.01 Mg ha^{-1} which resulted from the 0 kg K_2O ha^{-1} treatment and none of the K treatments were found to be significantly different from each other (Figure 29). The subsample did overestimate the maize yield by an average of an average of approximately 23%, with a range from 9 to 31% for the treatments.

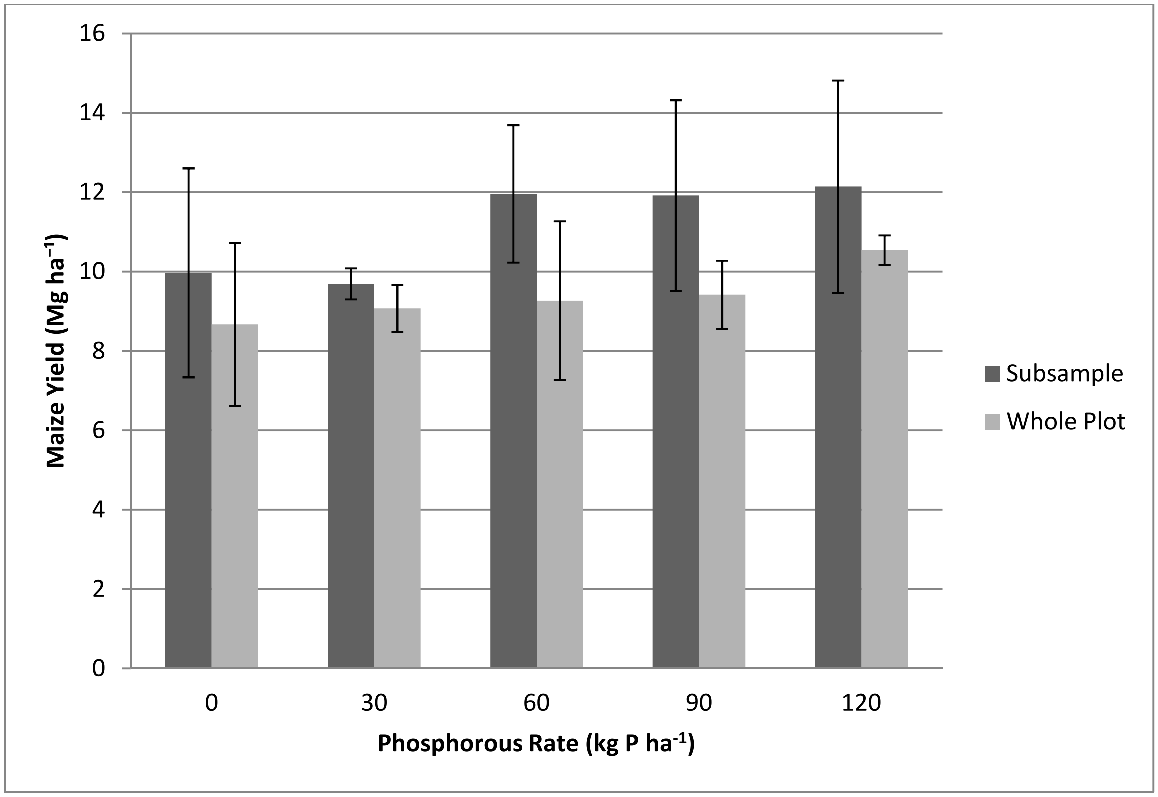

Figure 28. Mean maize yields for the P treatments for the subsample and whole plot analyses taken from Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

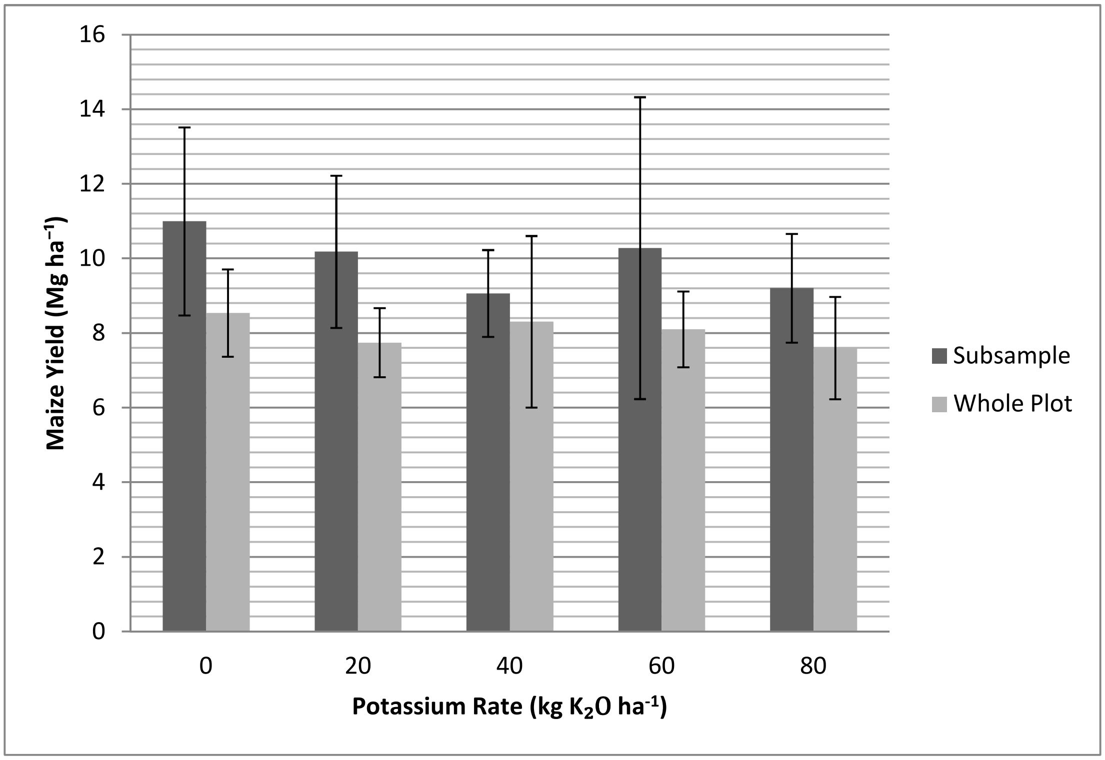

Figure 29. Mean maize yields for the K treatments for both the subsample and whole plot analyses taken from Maphutseng, Lesotho during the 2010-2011 growing season. Error bars are the standard deviations.

CONCLUSION

Overall, the trends described by the subsample results closely matched those from the whole plot in all the experiments. A difference was observed in the subsample was for the N treatment experiment, in which a positive response in grain production (ratio of grain weight to cobs plant^{-1}) was observed; this trend was not displayed in the whole plot statistical analysis. The plant population density experiment also showed significant results in the subsample and not the whole plot analysis; there was no difference between using more or fewer basins plot^{-1} to reach similar plant population densities; in other words, it was equally as effective to use more seeds basin^{-1} to reach a certain plant population density as it was to use more basins plot^{-1}. Because of the effort involved in digging the basins used in the Likoti method, it would be more beneficial to the smallholder farmer in Lesotho to use more seeds basin^{-1} when planting their maize crops at increasing plant population densities.

The results of the subsample were supported by the literature, but comparisons cannot be made at this point because of the absence of an accepted standard. While the trends from the subsample reflected those of the whole plot analysis, the subsample overestimated the yield for all experiments; this overestimation could be the result of bias by the person conducting the subsample. Human bias is inevitable, and in order for recommendations to be available for subsample methods the possible effects and interactions it has on the statistical analysis and the maize yield calculations would have to be investigated. In the case of this experiment, there was greater confidence in the data gathered from the subsample harvest rather than in the assessment of the whole plots because of fewer people and greater oversight involved in the collection. The discrepancy between measured yields from the subsample and whole field analyses may also be the result of possible losses from theft between the subsample harvest and the whole field harvest, which occurred later in the month. In the future, subsample and whole field harvesting should take place at the same time and with greater oversight of the harvesting process. Due to the lack of repeatable scientific studies, future research is recommended in order to progress towards developing a method for using a subsample to estimate the maize yield and investigate other main effects and interactions.

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APPENDIX

Table 19. Elemental soil analysis for top 5 cm from across the no-till field at the Maphutseng, Lesotho site. Samples were taken in February of 2011.

							ppm in soil (mg/kg)							meq/100 g			%		
Plot	pH	BpH	P	P (kg/ha)	K	K (kg/ha)	Ca	Mg	Zn	Mn	Cu	Fe	B	CEC	Acidity	Base Sat	Ca Sat	Mg Sat	K Sat
SNT1	6.53	6.17	23	51	53	117	376	40	1.7	13.9	0.1	23.2	0.3	21.5	89.1	10.9	8.7	1.5	0.6
SNT2	6.60	6.12	23	51	22	48	169	20	0.4	16.1	0.2	10.7	0.6	23.1	95.4	4.6	3.7	0.7	0.2
SNT3	6.65	6.19	29	64	121	266	374	74	1.2	16.3	0.3	17.0	0.4	20.9	86.7	13.3	9.0	2.9	1.5
SNT4	6.72	6.19	10	22	66	145	392	64	1.1	28.8	0.6	59.9	0.3	21.1	87.4	12.6	9.3	2.5	0.8

Table 20. Plot plan for the planting date, chemical & mechanical weed control treatment, and tillage type study conducted at Maphutseng during the 2009-2010 cropping season. The two tillage types were conventional tillage and conservation tillage. The three planting dates were 10/17, 11/17, and 12/17 2009. The four chemical and mechanical weed control treatments are Hand Hoeing (HH), Glyphosate and Hand Hoeing (RH), and Glyphosate and Flumetsulam and S-metolachlor (RB). The plot size for this study was 3 m by 10 m.

Conventional	Tillage			
10/17/2009	101 HH	102 RB	103 RH	104 RR
10/17/2009	105 RH	106 RR	107 RB	108 HH
10/17/2009	109 RH	110 RB	111 RR	112 RB
10/17/2009	113 HH	114 RH	115 RR	116 HH
11/17/2009	301 HH	302 RB	303 RH	304 RR
11/17/2009	305 RH	306 RR	307 RB	308 HH
11/17/2009	309 RH	310 RB	311 RR	312 RB
11/17/2009	313 HH	314 RH	315 RR	316 HH
12/17/2009	201 HH	202 RB	203 RH	204 RR
12/17/2009	205 RH	206 RR	207 RB	208 HH
12/17/2009	209 RH	210 RB	211 RR	212 RB
12/17/2009	213 HH	214 RH	215 RR	216 HH

Conservation	Tillage			
10/17/2009	101 RB	102 RR	103 HH	104 RH
10/17/2009	105 RB	106 RR	107 HH	108 RH
10/17/2009	109 RR	110 RH	111 RH	112 RB
10/17/2009	113 RB	114 RR	115 HH	116 HH
11/17/2009	301 RB	302 RR	303 HH	304 RH
11/17/2009	305 RB	306 RR	307 HH	308 RH
11/17/2009	309 RR	310 RH	311 RH	312 RB
11/17/2009	313 RB	314 RR	315 HH	316 HH
12/17/2009	201 RB	202 RR	203 HH	204 RH
12/17/2009	205 RB	206 RR	207 HH	208 RH
12/17/2009	209 RR	210 RH	211 RH	212 RB
12/17/2009	213 RB	214 RR	215 HH	216 HH

Table 21. Plot plan for the plant population study conducted at Maphutseng during the 2010-2011 cropping season. The five populations are as follows: 15,556 (1), 31,111 (2), 28,000 (3), 46.667 (4), and 56,000 (5) plants per hectare. The plot size was 10 m by 4.5 m.

Rep 1	1	5	2	4	3
Rep 2	2	3	5	1	4
Rep 3	3	4	1	5	2
Rep 4	5	2	4	3	1

Table 22. Plot plan for the population and nitrogen and phosphorus factorial experiment conducted at Maphutseng during the 2009-2010 cropping season. The treatments (T1-T9) consist of one nitrogen fertilizer rate and one phosphorus fertilizer rate (see Table 8). The plot size was 6 m by 3 m. The same plot plan was used for the three target populations used in this experiment.

Rep 1	101 T2	102 T6	103 T3
	104 T4	105 T7	106 T1
	107 T5	108 T8	109 T9
Rep 2	201 T5	202 T7	203 T2
	204 T4	205 T6	206 T8
	207 T1	208 T3	209 T9
Rep 3	301 T6	302 T7	303 T8
	304 T5	305 T4	306 T3
	307 T1	308 T9	309 T2
Rep 4	401 T1	402 T9	403 T5
	404 T2	405 T7	406 T6
	407 T3	408 T8	409 T4

Table 233. Plot plan for the nitrogen fertilizer application experiment conducted at Maphutseng and Roma during the 2010-2011 cropping season. The five N fertilizer rates are as follows: 0 (1), 50 (2), 100 (3), 150 (4), and 200 (5) kg N ha-1. The plot size was 10 m by 4.5m.

Rep 1	4	5	1	2	3
Rep 2	1	3	4	5	2
Rep 3	3	2	1	4	5
Rep 4	2	3	5	1	4

Table 24. Plot plan for the phosphorus fertilizer application experiment conducted at Maphutseng and Roma during the 2010-2011 cropping season. The five P_2O_5 fertilizer rates are as follows: 0 (1), 30 (2), 60 (3), 90 (4), and 120 (5) kg P ha-1. The plot size was 10 m by 4.5m.

Rep 1	1	4	2	3	5
Rep 2	2	5	4	1	3
Rep 3	3	2	1	5	4
Rep 4	5	1	3	4	2

Table 245. Plot plan for the potassium fertilizer application experiment conducted at Maphutseng and Roma during the 2010-2011 cropping season. The five K_2O fertilizer rates are as follows: 0 (1), 20 (2), 40 (3), 60 (4), and 80 (5) kg K ha-1. The plot size was 10 m by 4.5m.

Rep 1	4	5	1	3	2
Rep 2	1	4	3	2	5
Rep 3	2	1	4	5	3
Rep 4	3	2	5	4	1

Table 25. Raw data for the October planting date from the tilled plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

Planting Date	Plot NO	Treatment	Rep	Plot Pop	Plot Yld
PD1	101	HH	1	68	8.26
PD1	102	RB	1	49	5.72
PD1	103	RH	1	62	11.12
PD1	104	RR	1	63	5.97
PD1	105	RH	2	43	10.51
PD1	106	RR	2	50	6.84
PD1	107	RB	2	31	5.41
PD1	108	HH	2	42	7.31
PD1	109	RH	3	50	8.10
PD1	110	HH	3	45	7.54
PD1	111	RR	3	52	3.47
PD1	112	RB	3	39	5.04
PD1	113	RB	4	35	6.93
PD1	114	RH	4	54	9.77
PD1	115	RR	4	54	8.52
PD1	116	HH	4	56	6.58

Table 26. Raw data for the November planting date from the tilled plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

PD2	101	HH	1	37	8.59
PD2	102	RB	1	34	6.61
PD2	103	RH	1	29	5.62
PD2	104	RR	1	40	6.47
PD2	105	RH	2	40	9.02
PD2	106	RR	2	18	4.93
PD2	107	RB	2	21	4.34
PD2	108	HH	2	31	4.04
PD2	109	RH	3	48	4.45
PD2	110	HH	3	25	5.39
PD2	111	RR	3	31	4.51
PD2	112	RB	3	24	4.53
PD2	113	RB	4	50	8.14
PD2	114	RH	4	29	7.47
PD2	115	RR	4	25	6.41
PD2	116	HH	4	22	5.39

Table 27. Raw data for the December planting date from the tilled plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

PD3	101	HH	1	90	8.43
PD3	102	RB	1	73	7.95
PD3	103	RH	1	74	2.85
PD3	104	RR	1	68	5.69
PD3	105	RH	2	84	9.52
PD3	106	RR	2	61	7.06
PD3	107	RB	2	61	6.00
PD3	108	HH	2	75	5.22
PD3	109	RH	3	74	8.26
PD3	110	HH	3	89	5.93
PD3	111	RR	3	61	10.58
PD3	112	RB	3	64	6.46
PD3	113	RB	4	62	8.06
PD3	114	RH	4	61	6.76
PD3	115	RR	4	51	6.80
PD3	116	HH	4	56	6.71

Table 28. Raw data for the October planting date from the no-till plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

NTD1	101	HH	1	58	9.22
NTD1	102	RB	1	65	10.00
NTD1	103	HH	2	72	10.35
NTD1	104	RH	1	68	10.15
NTD1	105	RR	1	60	8.50
NTD1	106	RR	2	64	9.74
NTD1	107	RB	2	61	10.30
NTD1	108	RH	2	57	9.20
NTD1	109	RR	3	72	11.95
NTD1	110	RH	3	82	10.98
NTD1	111	RH	4	83	10.55
NTD1	112	RB	3	78	10.84
NTD1	113	RB	4	64	10.15
NTD1	114	RR	4	68	10.11
NTD1	115	HH	3	77	10.60
NTD1	116	HH	4	73	11.30

Table 29. Raw data for the November planting date from the no-till plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

NTD2	101	RB	1	35	9.06
NTD2	102	RR	1	26	6.57
NTD2	103	HH	1	23	6.80
NTD2	104	RH	1	22	5.86
NTD2	105	RB	2	31	5.18
NTD2	106	RR	2	33	7.26
NTD2	107	HH	2	31	2.84
NTD2	108	RH	2	21	2.38
NTD2	109	RR	3	31	6.28
NTD2	110	RH	3	24	5.12
NTD2	111	RH	4	18	4.59
NTD2	112	RB	3	25	2.88
NTD2	113	RB	4	22	3.60
NTD2	114	RR	4	23	4.29
NTD2	115	HH	3	30	4.07
NTD2	116	HH	4	24	2.67

Table 30. Raw data for the December planting date from the no-till plots from the Planting Date, Weed Control Treatment, and Tillage Type study conducted at Maphutseng, Lesotho during the 2009-2010 cropping season.

NTD3	101	RR	1	87	9.95
NTD3	102	RB	1	75	8.18
NTD3	103	HH	1	77	8.87
NTD3	104	RH	1	67	9.91
NTD3	105	RB	2	85	10.75
NTD3	106	RR	2	66	8.42
NTD3	107	HH	2	64	7.81
NTD3	108	RH	2	68	8.48
NTD3	109	RR	3	53	10.19
NTD3	110	RH	3	64	7.71
NTD3	111	RH	4	68	6.81
NTD3	112	RB	3	83	8.39
NTD3	113	RB	4	71	6.78
NTD3	114	RR	4	69	7.09
NTD3	115	HH	3	58	6.06
NTD3	116	HH	4	71	8.34

Table 31. Raw data for the population study conducted at Maphutseng during the 2010-2011 cropping season (Whole field sample).

	Plot	Trt #	Net Grain Weight (Kg) in 3 rows	Cob & Grain Weight (Kg) in 3 rows	Grain Moisture (%)	Number of Plants in 3 rows	Stover wet Wt (kg)	Stover Moisture %	Stover Dry Weight	moisture factor	population (plants/ha)	grain yield kg/ha	grain yield Mt/ha	dry yield Mt/ha
Maize Pop	101	1	18.64	22.46	15.00	62	10.25	0.19	8.30	1.005	24171.32	7266.99	7.27	7.30
MP	204	1	12.37	14.18	13.45	55	10.51	0.19	8.51	1.0205	21442.30	4822.57	4.82	4.92
MP	303	1	17.13	20.22	13.70	61	9.52	0.19	7.71	1.018	23781.46	6678.30	6.68	6.80
MP	405	1	12.27	14.86	12.80	62	9.20	0.19	7.45	1.027	24171.32	4783.58	4.78	4.91
MP	103	2	20.72	24.99	13.15	81	9.8	0.19	7.938	1.0235	31578.66	8077.90	8.08	8.27
MP	201	2	23.19	27.28	13.75	80	13.05	0.19	10.5705	1.0175	31188.80	9040.85	9.04	9.20
MP	305	2	15.03	17.37	13.25	86	11.51	0.19	9.3231	1.0225	33527.96	5859.60	5.86	5.99
MP	402	2	25.05	29.6	13.5	103	14.72	0.19	11.9232	1.02	40155.58	9765.99	9.77	9.96
MP	105	3	29.44	34.67	13.65	113	16.49	0.19	13.3569	1.0185	44054.18	11477.48	11.48	11.69
MP	202	3	17.91	21.14	13.25	55	9.44	0.19	7.6464	1.0225	21442.30	6982.39	6.98	7.14
MP	301	3	28.95	28.65	13.55	94	14.74	0.19	11.9394	1.0195	36646.84	11286.45	11.29	11.51
MP	404	3	25.05	26.51	13.9	105	14.39	0.19	11.6559	1.016	40935.30	9765.99	9.77	9.92
MP	104	4	25.97	30.76	13.95	115	13.3	0.19	10.773	1.0155	44833.90	10124.66	10.12	10.28
MP	205	4	15.01	17.82	13.8	101	18.83	0.19	15.2523	1.017	39375.86	5851.80	5.85	5.95
MP	302	4	25.72	39.86	14.55	118	16.2	0.19	13.122	1.0095	46003.48	10027.20	10.03	10.12
MP	403	4	25.97	29.99	13.95	111	14.18	0.19	11.4858	1.0155	43274.46	10124.66	10.12	10.28
MP	102	5	30.51	35.96	13.65	133	16.64	0.19	13.4784	1.0185	51851.38	11894.63	11.89	12.11
MP	203	5	9.08	18.61	13.65	75	12.06	0.19	9.7686	1.0185	29239.50	3539.93	3.54	3.61
MP	304	5	27.28	37.25	13.25	106	17.98	0.19	14.5638	1.0225	41325.16	10635.38	10.64	10.87
MP	401	5	30.5	36.16	13.4	125	14.16	0.19	11.4696	1.021	48732.50	11890.73	11.89	12.14

Table 32. Raw data for the population study conducted at Maphutseng (Subsample) during the 2010-2011 cropping season.

Treatment	Replicate	Plants per 5.55m			Mean	Plants/h	Cob wt.	Cob #	Grain wt	Moisture '	Test wt	Gr:Cob rat	Yield per ha	Moisture factor	Dry Yield
1	1	15	12	15	14	28000	5.58	19	4.2	18.8	54.7	0.75	11.8	0.97	11.4
1	2	10	12	11	11	22000	6.25	21	4.91	18.8	54.7	0.79	10.8	0.97	10.4
1	3	19	10	7	12	24000	4.03	13	3.22	18.6	52.5	0.80	7.7	0.97	7.5
1	4	6	10	12	9.3	18666.7	ND	17	4.1	20.5	53.6	#VALUE!	7.7	0.95	7.3
2	1	11	19	14	14.7	29333.3	6.25	19	4.76	21.1	53.4	0.76	14.0	0.94	13.2
2	2	11	13	16	13.3	26666.7	5.43	19	4.34	20.8	52.1	0.80	11.6	0.95	11.0
2	3	17	2	15	11.3	22666.7	4.45	15	3.56	19.7	52.5	0.80	8.1	0.96	7.7
2	4	28	27	22	25.7	51333.3	4.41	15	3.51	20.9	53.7	0.80	18.0	0.95	17.0
3	1	20	22	25	22.3	44666.7	4.98	15	3.84	21	54.3	0.77	17.2	0.95	16.2
3	2	17	17	13	15.7	31333.3	5.17	16	4.11	23.2	51.7	0.79	12.9	0.92	11.9
3	3	18	25	22	21.7	43333.3	4.98	16	3.98	19.8	53.8	0.80	17.2	0.96	16.5
3	4	25	22	19	22.0	44000	5.43	16	4.37	20.2	54.8	0.80	19.2	0.95	18.3
4	1	20	25	27	24.0	48000	4.97	16	3.8	20.9	54.6	0.76	18.2	0.95	17.3
4	2	17	21	20	19.3	38666.7	4.44	16	3.56	22	53	0.80	13.8	0.94	12.9
4	3	22	25	21	22.7	45333.3	3.4	12	2.76	21.7	52.2	0.81	12.5	0.94	11.7
4	4	23	24	28	25.0	50000	4.29	14	3.45	18.9	55.6	0.80	17.3	0.97	16.7
5	1	32	28	28	29.3	58666.7	3.77	11	2.85	21.4	54.5	0.76	16.7	0.94	15.7
5	2	28	23	27	26.0	52000	3.95	13	3.21	20.7	53.2	0.81	16.7	0.95	15.8
5	3	27	25	18	23.3	46666.7	3.75	12	3.08	19.4	54.6	0.82	14.4	0.96	13.8
5	4	29	30	21	26.7	53333.3	3.88	13	3.13	20.3	56.1	0.81	16.7	0.95	15.9

Table 33. Raw data for the N fertilizer experiment conducted at Maphutseng (whole field) during the 2010-2011 cropping season.

Plot	Trt #	Fertilizer Rate (kg ha^{-1})	Net Grain Weight (Kg) in 3 rows	Cob & Grain Weight (Kg) in 3 rows	Grain Moisture (%)	Number of Plants in 3 rows	Stover wet Wt (kg)	Stover Moisture %	Stover Dry Weight	moisture factor	population (plants/ha)	grain yield kg/ha	grain yield Mt/ha	dry yield Mt/ha
404.00	1.00		18.93	21.58	13.35	65.00	10.35	0.19	8.39	1.02	25340.90	7380.05	7.38	7.54
103.00	1.00		18.89	22.25	12.90	66.00	10.35	0.19	8.39	1.03	25730.76	7364.46	7.36	7.56
201.00	1.00		23.23	27.50	13.55	59.00	8.62	0.19	6.99	1.02	23001.74	9056.45	9.06	9.23
303.00	1.00		18.20	27.39	13.85	72.00	9.11	0.19	7.38	1.02	28069.92	7095.45	7.10	7.21
302.00	2.00		17.19	19.39	12.85	71.00	10.43	0.19	8.45	1.03	27680.06	6701.69	6.70	6.88
401.00	2.00		21.00	23.97	13.05	77.00	10.73	0.19	8.70	1.02	30019.22	8187.06	8.19	8.39
104.00	2.00		21.88	25.79	12.70	94.00	13.37	0.19	10.84	1.03	36646.84	8530.14	8.53	8.77
205.00	2.00		15.12	24.88	13.15	81.00	10.30	0.19	8.35	1.02	31578.66	5894.68	5.89	6.03
105.00	3.00		21.64	24.97	13.15	85.00	16.25	0.19	13.17	1.02	33138.10	8436.57	8.44	8.63
202.00	3.00		18.99	23.10	13.90	86.00	9.99	0.19	8.10	1.02	33527.96	7403.44	7.40	7.52
301.00	3.00		21.25	21.50	14.30	49.00	12.01	0.19	9.73	1.01	19103.14	8284.53	8.28	8.38
402.00	3.00		17.75	22.12	13.95	69.00	11.88	0.19	9.63	1.02	26900.34	6920.02	6.92	7.03
203.00	4.00		14.13	17.84	13.90	62.00	10.33	0.19	8.37	1.02	24171.32	5508.72	5.51	5.60
304.00	4.00		19.69	23.61	13.70	75.00	9.78	0.19	7.93	1.02	29239.50	7676.34	7.68	7.81
101.00	4.00		19.14	27.89	14.20	69.00	11.86	0.19	9.61	1.01	26900.34	7461.92	7.46	7.56
405.00	4.00		24.74	23.10	13.70	68.00	10.16	0.19	8.23	1.02	26510.48	9645.14	9.65	9.82
204.00	5.00		13.85	11.52 (2)	13.25	62.00	9.26	0.19	7.50	1.02	24171.32	5399.56	5.40	5.52
305.00	5.00		15.75	12.6(2)	13.45	67.00	11.14	0.19	9.03	1.02	26120.62	6140.30	6.14	6.27
403.00	5.00		14.47	15.30	13.25	47.00	8.36	0.19	6.77	1.02	18323.42	5641.27	5.64	5.77
102.00	5.00		18.05	21.77	13.60	66.00	10.26	0.19	8.31	1.02	25730.76	7036.97	7.04	7.17

Table 34. Raw data for the N fertilizer experiment conducted at Maphutseng (subsample field) during the 2010-2011 cropping season.

Treatment	Replicate	Plants per 5.55m			Mean	Population pe	Cob wt.	Cob #	Grain wt	Moisture '	Test wt	Gr:Cob rat	Yield per l	Moisture '	Dry Yield
Nitrogen 1 (0kg)	1	15	16	15	15.3	30666.7	4.85	20	3.84	21.5	52.8	0.79	11.78	0.94	11.07
Nitrogen 1 (0kg)	2	11	11	12	11.3	22666.7	5.33	18	4.14	22.8	52	0.78	9.38	0.93	8.70
Nitrogen 1 (0kg)	3	15	13	15	14.3	28666.7	5.08	18	4.04	21.1	51.7	0.80	11.58	0.94	10.93
Nitrogen 1 (0kg)	4	13	14	11	12.7	25333.3	6.93	23	5.41	22.3	52.1	0.78	13.71	0.93	12.77
Nitrogen 2 (50kg)	1	17	22	15	18.0	36000.0	4.14	15	3.35	20.6	53	0.81	12.06	0.95	11.44
Nitrogen 2 (50kg)	2	14	12	13	13.0	26000.0	4.87	18	3.86	21.4	52.4	0.79	10.04	0.94	9.44
Nitrogen 2 (50kg)	3	15	17	18	16.7	33333.3	4.93	17	3.81	22.3	50.4	0.77	12.70	0.93	11.84
Nitrogen 2 (50kg)	4	15	21	18	18.0	36000.0	5.08	19	3.96	20	53.4	0.78	14.26	0.96	13.61
Nitrogen 3 (100kg)	1	18	18	17	17.7	35333.3	5.44	18	4.18	22.8	51.9	0.77	14.77	0.93	13.69
Nitrogen 3 (100kg)	2	13	17	10	13.3	26666.7	5.4	17	4.23	21.1	52.2	0.78	11.28	0.94	10.65
Nitrogen 3 (100kg)	3	14	9	19	14.0	28000.0	5.62	18	4.33	22.6	52.3	0.77	12.12	0.93	11.26
Nitrogen 3 (100kg)	4	11	16	14	13.7	27333.3	5.97	19	4.6	23.1	49.3	0.77	12.57	0.92	11.62
Nitrogen 4 (150kg)	1	10	15	14	13.0	26000.0	6.35	17	4.94	23.8	51.5	0.78	12.84	0.92	11.78
Nitrogen 4 (150kg)	2	10	12	7	9.7	19333.3	5.34	16	4.19	21.5	51.5	0.78	8.10	0.94	7.61
Nitrogen 4 (150kg)	3	11	17	14	14.0	28000.0	5.98	19	4.65	22.4	52.1	0.78	13.02	0.93	12.12
Nitrogen 4 (150kg)	4	14	7	21	14.0	28000.0	6.26	20	4.93	22.1	52.2	0.79	13.80	0.93	12.89
Nitrogen 5 (200kg)	1	14	19	17	16.7	33333.3	6.2	18	4.77	23.1	52.2	0.77	15.90	0.92	14.69
Nitrogen 5 (200kg)	2	9	15	13	12.3	24666.7	5.8	17	4.48	23.4	50.4	0.77	11.05	0.92	10.18
Nitrogen 5 (200kg)	3	10	12	7	9.7	19333.3	6.25	20	4.88	23.7	49.9	0.78	9.43	0.92	8.66
Nitrogen 5 (200kg)	4	10	13	17	13.3	26666.7	6.34	18	4.8	21.9	51.8	0.76	12.80	0.94	11.98

Table 35. Raw data for the N fertilizer experiment conducted at Roma during the 2010-2011 cropping season.

Plot #	Nutrient	Rate	Weight of cobs & Grain in 2 rows (Kg)	Net weight of Grain in 2 rows (kg)	percent Moisture	moisture factor	grain yield (kg/ha)	grain yield Mt/ha	dry yield Mt/ha
102	Nitrogen	0	3.91	2.98	14.1	1.014	1655.569	1.66	1.68
202	Nitrogen	0	3.49	2.82	16.1	0.994	1566.679	1.57	1.56
303	Nitrogen	0	3.34	5.35	14.3	1.012	2972.246	2.97	3.01
404	Nitrogen	0	4.22	4.02	13.3	1.022	2233.351	2.23	2.28
101	Nitrogen	50	3.88	3.02	14.0	1.015	1677.791	1.68	1.70
203	Nitrogen	50	4.51	6.38	16.0	0.995	3544.473	3.54	3.53
304	Nitrogen	50	6.53	5.26	14.3	1.012	2922.246	2.92	2.96
401	Nitrogen	50	4.95	3.86	14.6	1.009	2144.462	2.14	2.16
104	Nitrogen	100	2.81	2.24	13.9	1.016	1244.454	1.24	1.26
204	Nitrogen	100	6.22	4.86	16.1	0.994	2700.022	2.70	2.68
302	Nitrogen	100	2.35	1.84	12.5	1.03	1022.23	1.02	1.05
403	Nitrogen	100	6.55	5.09	14.1	1.014	2827.8	2.83	2.87
105	Nitrogen	150	6.51	5.15	14.5	1.01	2861.134	2.86	2.89
205	Nitrogen	150	5.69	4.47	15.8	0.997	2483.353	2.48	2.48
305	Nitrogen	150	6.67	5.29	16.1	0.994	2938.912	2.94	2.92
405	Nitrogen	150	3.76	3.42	13.8	1.017	1900.015	1.90	1.93
103	Nitrogen	200	5.49	4.32	14.1	1.014	2400.019	2.40	2.43
201	Nitrogen	200	4.89	3.75	16.5	0.99	2083.35	2.08	2.06
301	Nitrogen	200	2.13	1.63	14.4	1.011	905.5628	0.91	0.92
402	Nitrogen	200	4.65	3.65	13.9	1.016	2027.794	2.03	2.06

Table 36. Raw data for the P fertilizer experiment conducted at Maphutseng (whole field) during the 2010-2011 cropping season.

Plot	Trt #	Fertilizer Rate (kg ha^{-1})	Net Grain Weight (Kg) in 3 rows	Cob & Grain Weight (Kg) in 3 rows	Grain Moisture (%)	Number of Plants in 3 rows	Stover wet Wt (kg)	Stover Moisture %	Stover Dry Weight	moisture factor	population (plants/ha)	grain yield kg/ha	grain yield Mt/ha	dry yield Mt/ha
101	1	0	19.6	22.64	15.1	52	10.1	0.1896	8.18504	1.004	20272.72	7641.26	7.64	7.67
204	1	0	10	12.04	14.2	36	11.88	0.1896	9.627552	1.013	14034.96	3898.60	3.90	3.95
303	1	0	21.47	25.59	14.75	79	8.3	0.1896	6.72632	1.0075	30798.94	8370.29	8.37	8.43
402	1	0	19.65	24.65	15.25	58	11.02	0.1896	8.930608	1.0025	22611.88	7660.75	7.66	7.68
103	2	30	21.32	18.72(3)	14.3	76	9.38	0.1896	7.601552	1.012	29629.36	8311.82	8.31	8.41
201	2	30	18.99	24.38	14.5	72	10.96	0.1896	8.881984	1.01	28069.92	7403.44	7.40	7.48
302	2	30	18.36	22.04	15.2	70	10.76	0.1896	8.719904	1.003	27290.20	7157.83	7.16	7.18
405	2	30	17.1	25.21	14.1	61	11.84	0.1896	9.595136	1.014	23781.46	6666.61	6.67	6.76
104	3	60	15.54	18.58	13.5	69	12.7	0.1896	10.29208	1.02	26900.34	6058.42	6.06	6.18
205	3	60	15.54	18.58	13.7	60	11.75	0.1896	9.5222	1.018	23391.60	6058.42	6.06	6.17
301	3	60	26.71	26.33	14.8	55	11.66	0.1896	9.449264	1.007	21442.30	10413.16	10.41	10.49
403	3	60	18.55	21.19	15	71	9.86	0.1896	7.990544	1.005	27680.06	7231.90	7.23	7.27
102	4	90	16.8	19.87	14.65	69	10.96	0.1896	8.881984	1.0085	26900.34	6549.65	6.55	6.61
203	4	90	21.78	21.29(5)	13.8	83	9.99	0.1896	8.095896	1.017	32358.38	8491.15	8.49	8.64
305	4	90	19.38	28.62	13.8	75	8.34	0.1896	6.758736	1.017	29239.50	7555.49	7.56	7.68
404	4	90	20.13	18.27(3)	13.8	73	7.11	0.1896	5.761944	1.017	28459.78	7847.88	7.85	7.98
105	5	120	22.36	26.77	14.65	82	11.86	0.1896	9.611344	1.0085	31968.52	8717.27	8.72	8.79
202	5	120	21.71	26.22	15.15	90	10.93	0.1896	8.857672	1.0035	35087.40	8463.86	8.46	8.49
304	5	120	23.89	28.66	13.7	50	5.95	0.1896	4.82188	1.018	19493.00	9313.76	9.31	9.48
401	5	120	21.94	26.54	14.25	56	10.54	0.1896	8.541616	1.0125	21832.16	8553.53	8.55	8.66

Table 37. Raw data for the P fertilizer experiment conducted at Maphutseng (subsample) during the 2010-2011 cropping season.

Treatment	Replicate	Plants per 5.55m			Mean	Populatio	Cob wt.	Cob #	Grain wt	Moisture	Test wt	Gr:Cob rat	Yield per	Moisture	Dry Yield
Phosphorus 1 (0kg)	1	7	13	10	10.0	20000.0	7.1	22	5.5	21.1	50.6	0.77	11.00	0.94	10.38
Phosphorus 1 (0kg)	2	7	7	8	7.3	14666.7	5.98	21	4.63	23.5	50.1	0.77	6.79	0.92	6.25
Phosphorus 1 (0kg)	3	16	18	13	15.7	31333.3	5.48	18	4.28	22.9	47.5	0.78	13.41	0.93	12.42
Phosphorus 1 (0kg)	4	11	13	13	12.3	24666.7	6.34	19	4.8	23.9	47.3	0.76	11.84	0.92	10.85
Phosphorus 2 (30kg/h	1	11	17	14	14.0	28000.0	5.29	17	3.91	23.8	47.9	0.74	10.95	0.92	10.04
Phosphorus 2 (30kg/h	2	11	15	10	12.0	24000.0	5.89	18	4.52	23.2	49.5	0.77	10.85	0.92	10.01
Phosphorus 2 (30kg/h	3	8	11	11	10.0	20000.0	6.5	19	5.05	22.5	50.3	0.78	10.10	0.93	9.39
Phosphorus 2 (30kg/h	4	10	11	13	11.3	22666.7	5.93	19	4.49	24	48.9	0.76	10.18	0.92	9.31
Phosphorus 3 (60kg/h	1	11	14	19	14.7	29333.3	6.66	21	5.18	23.2	50.3	0.78	15.19	0.92	14.02
Phosphorus 3 (60kg/h	2	10	12	10	10.7	21333.3	6.56	22	5.09	25.1	45.8	0.78	10.86	0.90	9.82
Phosphorus 3 (60kg/h	3	14	15	11	13.3	26666.7	6.28	19	4.77	23.1	48.8	0.76	12.72	0.92	11.75
Phosphorus 3 (60kg/h	4	13	15	17	15.0	30000.0	5.83	18	4.46	24.1	50.6	0.77	13.38	0.91	12.23
Phosphorus 4 (90kg)	1	13	13	7	11.0	22000.0	6.33	19	4.77	24.4	47.4	0.75	10.49	0.91	9.56
Phosphorus 4 (90kg)	2	18	14	18	16.7	33333.3	6.35	20	4.89	23.6	48.8	0.77	16.30	0.92	14.98
Phosphorus 4 (90kg)	3	7	14	14	11.7	23333.3	6.08	19	4.75	20.4	51.3	0.78	11.08	0.95	10.54
Phosphorus 4 (90kg)	4	15	15	17	15.7	31333.3	5.76	19	4.41	24.4	49.3	0.77	13.82	0.91	12.59
Phosphorus 5 (120kg)	1	10	18	17	15.0	30000.0	6.14	19	4.76	21.3	51.9	0.78	14.28	0.94	13.45
Phosphorus 5 (120kg)	2	14	15	16	15.0	30000.0	6.42	18	4.91	24.1	48.6	0.76	14.73	0.91	13.46
Phosphorus 5 (120kg)	3	10	14	6	10.0	20000.0	5.68	19	4.34	21.9	50.4	0.76	8.68	0.94	8.12
Phosphorus 5 (120kg)	4	15	15	18	16.0	32000.0	6.13	18	4.63	24.3	49	0.76	14.82	0.91	13.51

Table 38. Raw data for the P fertilizer experiment conducted at Roma during the 2010-2011 cropping season.

Plot #	Nutrient	Rate	Weight of cobs & Grain in 2 rows (Kg)	Net weight of Grain in 2 rows (kg)	percent Moisture	moisture factor	grain yield (kg/ha)	grain yield Mt/ha	dry yield Mt/ha
102	Phosphorus	0	5.27	4.01	14.4	1.011	2227.796	2.23	2.25
202	Phosphorus	0	1.94	1.45	14.6	1.009	805.562	0.81	0.81
303	Phosphorus	0	3.80	2.93	15.0	1.005	1627.791	1.63	1.64
404	Phosphorus	0	4.23	3.17	14.9	1.006	1761.125	1.76	1.77
101	Phosphorus	30	7.01	5.49	14.6	1.009	3050.024	3.05	3.08
203	Phosphorus	30	1.63	1.28	13.1	1.024	711.1168	0.71	0.73
304	Phosphorus	30	2.69	2.19	13.4	1.021	1216.676	1.22	1.24
401	Phosphorus	30	7.38	6.48	15.5	1	3600.029	3.60	3.60
104	Phosphorus	60	1.81	1.44	12.8	1.027	800.0064	0.80	0.82
204	Phosphorus	60	0.98	0.84	13.2	1.023	466.6704	0.47	0.48
302	Phosphorus	60	3.47	2.32	13.2	1.023	1288.899	1.29	1.32
403	Phosphorus	60	2.73	2.14	12.8	1.027	1188.898	1.19	1.22
105	Phosphorus	90	2.16	1.68	13.5	1.02	933.3408	0.93	0.95
205	Phosphorus	90	1.13	0.91	16.9	0.986	505.5596	0.51	0.50
305	Phosphorus	90	0.36	0.31	**	1.003667	172.2236	0.17	0.17
405	Phosphorus	90	2.30	1.80	15.0	1.005	1000.008	1.00	1.01
103	Phosphorus	120	2.07	1.66	14.1	1.014	922.2296	0.92	0.94
201	Phosphorus	120	3.11	2.43	15.4	1.001	1350.011	1.35	1.35
301	Phosphorus	120	4.25	3.32	15.5	1	1844.459	1.84	1.84
402	Phosphorus	120	2.22	1.76	14.7	1.008	977.7856	0.98	0.99

Table 39. Raw data for the K fertilizer experiment conducted at Maphutseng (wholefield) during the 2010-2011 cropping season.

Plot	Trt #	Fertilizer Rate (kg ha^{-1})	Net Grain Weight (Kg) in 3 rows	Cob & Grain Weight (Kg) in 3 rows	Grain Moisture (%)	Number of Plants in 3 rows	Stover wet Wt (kg)	Stover Moisture %	Stover Dry Weight	moisture factor	population (plants/ha)	grain yield kg/ha	grain yield Mt/ha	dry yield Mt/ha
103	1		16.34	14.55(3)	14.76667	72	10.2	0.1896	8.26608	1.007333	28069.92	6370.31	6.37	6.42
201	1		16.36	19.909	15.4	78	9.58	0.1896	7.763632	1.001	30409.08	6378.11	6.38	6.38
302	1		22.24	13.72(2)	15.25	75	11.42	0.1896	9.254768	1.0025	29239.50	8670.49	8.67	8.69
405	1		15.55	18.23	14.1	53	5.47	0.1896	4.432888	1.014	20662.58	6062.32	6.06	6.15
105	2		16.68	20.15	13.8	65	10.05	0.1896	8.14452	1.017	25340.90	6502.86	6.50	6.61
204	2		12.28	14.64	17.16667	50	7.5	0.1896	6.078	0.983333	19493.00	4787.48	4.79	4.71
301	2		16.03	19.77	14.575	75	9.53	0.1896	7.723112	1.00925	29239.50	6249.46	6.25	6.31
402	2		17.09	20.71	14.775	67	10.68	0.1896	8.655072	1.00725	26120.62	6662.71	6.66	6.71
104	3		21.16	22.47	14.5	66	12.32	0.1896	9.984128	1.01	25730.76	8249.44	8.25	8.33
203	3		14.16	17.38	18.13333	74	8.91	0.1896	7.220664	0.973667	28849.64	5520.42	5.52	5.38
305	3		22.09	20.38(4)	13.9	65	8.24	0.1896	6.677696	1.016	25340.90	8612.01	8.61	8.75
401	3		10.59	12.99	15.2	53	7.34	0.1896	5.948336	1.003	20662.58	4128.62	4.13	4.14
101	4		17.7	16.57(3)	16.025	69	11.98	0.1896	9.708592	0.99475	26900.34	6900.52	6.90	6.86
202	4		18.25	22.16	21.825	86	9.6	0.1896	7.77984	0.93675	33527.96	7114.95	7.11	6.66
303	4		18.25	10.74(2)	14.73333	60	9.71	0.1896	7.868984	1.007667	23391.60	7114.95	7.11	7.17
404	4		12.35	10.2(2)	13.9	49	6.1	0.1896	4.94344	1.016	19103.14	4814.77	4.81	4.89
102	5		20.49	24.67	15.98	88	13.41	0.1896	10.86746	0.9952	34307.68	7988.23	7.99	7.95
205	5		15.62	18.52	14.875	52	6.79	0.1896	5.502616	1.00625	20272.72	6089.61	6.09	6.13
304	5		12.01	16.84	13.6	55	8.95	0.1896	7.25308	1.019	21442.30	4682.22	4.68	4.77
403	5		12.95	20.3	14.875	60	7.11	0.1896	5.761944	1.00625	23391.60	5048.69	5.05	5.08

Table 40. Raw data for the K fertilizer experiment conducted at Maphutseng (subsample) during the 2010-2011 cropping season.

Treatment	Replicate	Plants per 5.55m			Mean	Populatio	Cob wt.	Cob #	Grain wt	Moisture	Test wt	Gr:Cob rat	Yield per l	Moisture	Dry Yield
Potassium 1 (0kg)	1	19	9	18	15.3	30666.7	6.42	20	4.89	23.2	47.5	0.76	15.00	0.92	13.84
Potassium 1 (0kg)	2	10	17	12	13.0	26000.0	6.03	20	4.5	23.6	48.1	0.75	11.70	0.92	10.75
Potassium 1 (0kg)	3	14	18	11	14.3	28666.7	5.83	18	4.37	22.7	49.2	0.75	12.53	0.93	11.63
Potassium 1 (0kg)	4	10	10	9	9.7	19333.3	5.46	20	4.22	20.4	49.9	0.77	8.16	0.95	7.76
Potassium 2 (20kg/ha)	1	14	13	12	13.0	26000.0	5.02	18	3.77	23.8	49.7	0.75	9.80	0.92	8.99
Potassium 2 (20kg/ha)	2	6	11	10	9.0	18000.0	6.18	21	4.73	22.4	51.1	0.77	8.51	0.93	7.93
Potassium 2 (20kg/ha)	3	12	16	13	13.7	27333.3	6.23	19	4.75	22.9	50.4	0.76	12.98	0.93	12.02
Potassium 2 (20kg/ha)	4	13	14	10	12.3	24666.7	6.51	19	5.03	20.5	51.9	0.77	12.41	0.95	11.79
Potassium 3 (40kg/ha)	1	11	12	13	12.0	24000.0	6.09	20	4.67	21.8	51.1	0.77	11.21	0.94	10.50
Potassium 3 (40kg/ha)	2	8	7	14	9.7	19333.3	6.52	20	4.94	24.6	49.5	0.76	9.55	0.91	8.68
Potassium 3 (40kg/ha)	3	9	11	13	11.0	22000.0	5.72	20	4.5	21.2	50	0.79	9.90	0.94	9.34
Potassium 3 (40kg/ha)	4	7	9	14	10.0	20000.0	5.36	19	4.12	21.7	51.2	0.77	8.24	0.94	7.73
Potassium 4 (60kg/ha)	1	8	15	16	13.0	26000.0	6.3	20	4.75	21.3	49.5	0.75	12.35	0.94	11.63
Potassium 4 (60kg/ha)	2	18	15	18	17.0	34000.0	6.34	19	4.87	22.8	51.1	0.77	16.56	0.93	15.35
Potassium 4 (60kg/ha)	3	7	9	12	9.3	18666.7	5.94	20	4.51	23.7	48.8	0.76	8.42	0.92	7.73
Potassium 4 (60kg/ha)	4	5	11	6	7.3	14666.7	5.87	21	4.55	19.6	50.7	0.78	6.67	0.96	6.40
Potassium 5 (80kg/ha)	1	13	15	17	15.0	30000.0	5.64	19	4.06	25.7	49.9	0.72	12.18	0.90	10.94
Potassium 5 (80kg/ha)	2	12	9	10	10.3	20666.7	6.57	21	5.05	21.2	50.4	0.77	10.44	0.94	9.84
Potassium 5 (80kg/ha)	3	9	9	11	9.7	19333.3	6.08	19	4.69	24	49.5	0.77	9.07	0.92	8.30
Potassium 5 (80kg/ha)	4	9	6	15	10.0	20000.0	5.43	18	4.12	21.6	49	0.76	8.24	0.94	7.74

Table 41. Raw data for the K fertilizer experiment conducted at Roma during the 2010-2011 cropping season.

Plot #	Nutrient	Rate	Weight of cobs & Grain in 2 rows (Kg)	Net weight of Grain in 2 rows (kg)	percent Moisture	moisture factor	grain yield (kg/ha)	grain yield Mt/ha	dry yield Mt/ha
102	Potassium	0	1.16	0.89	14.9	1.006	494.4484	0.49	0.50
202	Potassium	0	6.76	5.29	13.6	1.019	2938.912	2.94	2.99
303	Potassium	0	3.07	2.43	14.3	1.012	1350.011	1.35	1.37
404	Potassium	0	0.91	1.03	16.0	0.995	572.2268	0.57	0.57
101	Potassium	20	5.34	3.99	14.9	1.006	2216.684	2.22	2.23
203	Potassium	20	9.20	7.33	13.9	1.016	4072.255	4.07	4.14
304	Potassium	20	6.16	4.88	14.6	1.009	2711.133	2.71	2.74
401	Potassium	20	1.65	1.25	15.8	0.997	694.45	0.69	0.69
104	Potassium	40	7.74	6.10	13.5	1.02	3388.916	3.39	3.46
204	Potassium	40	11.31	8.27	15.1	1.004	4594.481	4.59	4.61
302	Potassium	40	2.25	1.77	13.9	1.016	983.3412	0.98	1.00
403	Potassium	40	3.26	2.55	14.1	1.014	1416.678	1.42	1.44
105	Potassium	60	9.64	5.29	14.9	1.006	2938.912	2.94	2.96
205	Potassium	60	13.45	10.74	14.9	1.006	5966.714	5.97	6.00
305	Potassium	60	8.00	6.46	14.1	1.014	3588.918	3.59	3.64
405	Potassium	60	7.62	5.95	13.2	1.023	3305.582	3.31	3.38
103	Potassium	80	9.01	7.08	14.1	1.014	3933.365	3.93	3.99
201	Potassium	80	9.79	1.25	13.6	1.019	694.45	0.69	0.71
301	Potassium	80	3.23	2.47	14.4	1.011	1372.233	1.37	1.39
402	Potassium	80	2.14	1.78	14.3	1.012	988.8968	0.99	1.00

Table 42. Raw data for population one from the population and N/P factorial conducted at Maphutseng during the 2009-2010 cropping season.

Plot	Rep	TRT	N	P	POP	PlotPOP	soil N	soil P	soil K	soil OC	pH w	pH kcl	PlotYlds
101	1	2	0	50	17777	40	1.21	0.23	1.18	0.50	5.97	5.52	5.36
102	1	6	30	100	17777	35	2.34	0.25	1.14	0.86	5.84	5.01	6.11
103	1	3	0	100	17777	33	1.48	0.29	1.16	1.98	6.16	5.39	4.36
104	1	4	30	0	17777	40	2.30	0.45	1.26	0.94	6.39	5.84	5.00
105	1	7	60	0	17777	40	1.50	0.24	1.17	0.99	6.68	5.35	5.50
106	1	1	0	0	17777	39	1.74	0.47	1.45	1.80	5.77	5.33	3.71
107	1	5	30	50	17777	40	1.81	0.54	1.14	1.43	5.75	5.74	6.94
108	1	8	60	50	17777	42	1.58	0.19	1.17	0.48	5.72	5.35	6.18
109	1	9	60	100	17777	40	1.86	0.15	1.16	1.55	5.21	4.43	6.34
201	2	5	30	50	17777	36	1.28	0.27	1.17	0.87	5.73	5.57	5.26
202	2	7	60	0	17777	41	1.18	0.24	1.17	0.86	5.9	5.19	4.55
203	2	2	0	50	17777	40	1.30	0.23	1.24	1.43	6.24	5.68	5.71
204	2	4	30	0	17777	33	1.13	0.53	1.32	0.50	6.09	5.46	3.17
205	2	6	30	100	17777	31	1.91	0.18	1.19	0.29	5.14	4.76	3.82
206	2	8	60	50	17777	36	0.92	0.54	1.31	0.63	5.92	5.19	7.06
207	2	1	0	0	17777	41	0.97	0.21	1.21	1.30	5.62	5.12	4.35
208	2	3	0	100	17777	40	1.13	0.26	1.34	0.85	6.16	5.62	5.44
209	2	9	60	100	17777	44	0.97	0.20	1.30	1.83	5.93	5.88	5.95
301	3	6	30	100	17777	39	0.80	0.38	1.17	1.78	6.26	5.27	4.15
302	3	7	60	0	17777	38	2.18	0.27	1.41	1.02	5.9	5.19	4.28
303	3	8	60	50	17777	39	1.02	0.29	1.42	1.84	6.06	5.53	3.68
304	3	5	30	50	17777	39	2.52	0.26	1.24	1.81	5.88	5.44	4.95
305	3	4	30	0	17777	40	2.68	0.25	1.48	1.31	5.45	5.33	3.52
306	3	3	0	100	17777	41	0.59	0.25	1.32	1.92	5.75	5.21	4.66
307	3	1	0	0	17777	38	2.79	0.38	1.48	1.76	6.02	6.51	4.41
308	3	9	60	100	17777	40	1.27	0.25	1.35	1.76	5.72	5.5	6.11
309	3	2	0	50	17777	39	2.29	0.26	1.37	2.09	5.34	5.17	5.19
401	4	1	0	0	17777	38	1.36	0.20	1.68	1.88	5.95	5.3	4.81
402	4	9	60	100	17777	38	2.18	0.26	1.34	0.49	6.35	5.41	3.76
403	4	5	30	50	17777	40	2.25	0.21	1.35	3.27	5.56	5.01	9.01
404	4	2	0	50	17777	38	1.08	0.26	1.68	2.25	5.21	4.53	5.21
405	4	7	60	0	17777	40	1.32	0.27	1.38	1.84	6.03	5.42	4.50
406	4	6	30	100	17777	38	1.46	0.25	1.37	0.90	5.96	5.42	4.17
407	4	3	0	100	17777	38	1.16	0.57	1.48	2.57	5.88	5.49	6.09
408	4	8	60	50	17777	40	2.61	0.19	1.30	1.88	6.3	5.7	5.76
409	4	4	30	0	17777	40	0.54	0.22	1.36	2.09	5.99	5.52	9.47

Table 43. Raw data for population two from the population and N/P factorial conducted at Maphutseng during the 2009-2010 cropping season.

101	1	2	0	50	35554	58	1.17	0.23	1.82	1.59	6.01	5.59	5.15
102	1	6	30	100	35554	70	1.44	0.18	1.89	0.90	5.88	5.71	6.06
103	1	3	0	100	35554	66	2.55	0.26	1.68	0.90	6	5.81	5.97
104	1	4	30	0	35554	73	1.64	0.24	1.79	1.30	5.93	5.72	4.19
105	1	7	60	0	35554	71	1.99	0.24	1.70	1.18	5.74	5.62	4.35
106	1	1	0	0	35554	67	2.62	0.25	1.73	0.82	6.23	5.66	4.33
107	1	5	30	50	35554	71	2.79	0.25	1.79	3.00	5.71	5.14	4.76
108	1	8	60	50	35554	65	1.06	0.18	1.89	1.06	5.46	5.26	6.81
109	1	9	60	100	35554	70	2.33	0.24	2.38	1.43	6.05	5.77	6.81
201	2	5	30	50	35554	69	1.35	0.25	1.65	2.12	5.75	5.4	6.73
202	2	7	60	0	35554	69	1.02	0.19	1.85	0.73	5.62	5.49	5.28
203	2	2	0	50	35554	72	1.33	0.24	1.91	1.36	6.09	5.49	2.49
204	2	4	30	0	35554	55	2.52	0.20	1.66	0.74	6.83	5.49	4.25
205	2	6	30	100	35554	64	1.11	0.34	1.92	0.61	5.72	5.41	5.17
206	2	8	60	50	35554	68	1.43	0.21	2.34	2.08	5.75	5.28	6.20
207	2	1	0	0	35554	47	1.46	0.54	1.79	1.20	5.68	5.34	3.59
208	2	3	0	100	35554	63	2.68	0.34	2.13	0.90	5.95	5.38	5.36
209	2	9	60	100	35554	56	2.85	0.31	1.85	0.78	5.95	5.63	5.64
301	3	6	30	100	35554	58	1.78	0.25	1.91	1.63	5.88	5.52	4.81
302	3	7	60	0	35554	74	1.29	0.22	1.94	2.25	5.66	5.57	6.64
303	3	8	60	50	35554	52	2.93	0.27	1.84	1.26	5.82	5.68	5.07
304	3	5	30	50	35554	60	0.74	0.24	1.89	1.61	5.62	5.5	4.86
305	3	4	30	0	35554	69	1.78	0.27	1.98	0.61	6.25	5.26	4.65
306	3	3	0	100	35554	61	1.33	0.25	1.73	1.63	6.02	5.45	6.44
307	3	1	0	0	35554	47	1.11	0.21	1.98	1.51	6.02	5.38	3.04
308	3	9	60	100	35554	57	2.48	0.22	1.85	1.92	6.23	5.21	5.00
309	3	2	0	50	35554	72	1.31	0.47	1.99	2.05	5.94	5.65	4.41
401	4	1	0	0	35554	67	2.78	0.21	1.82	1.42	6.18	5.36	3.39
402	4	9	60	100	35554	71	2.55	0.31	2.38	2.94	6.14	5.68	6.71
403	4	5	30	50	35554	76	2.48	0.41	2.05	1.71	5.87	5.44	3.16
404	4	2	0	50	35554	39	1.35	0.26	2.24	2.00	6.24	5.54	3.85
405	4	7	60	0	35554	64	2.77	0.22	2.03	1.27	6.18	5.84	5.16
406	4	6	30	100	35554	61	1.64	0.26	1.91	1.10	6.03	5.72	7.80
407	4	3	0	100	35554	45	1.54	0.17	2.01	2.00	6.35	5.78	5.86
408	4	8	60	50	35554	60	0.50	0.17	2.01	1.63	6.32	5.85	5.08
409	4	4	30	0	35554	58	1.43	0.23	1.79	2.16	5.72	5.22	6.98

Table 44. Raw data for population three from the population and N/P factorial conducted at Maphutseng during the 2009-2010 cropping season.

101	1	2	0	50	53331	107	1.32	0.29	1.20	1.90	5.88	5.53	4.82
102	1	6	30	100	53331	114	2.45	0.32	1.10	0.41	6.23	5.59	4.88
103	1	3	0	100	53331	88	0.96	0.25	1.05	0.78	6.2	5.2	5.16
104	1	4	30	0	53331	117	2.49	0.22	1.13	1.35	6.13	5.57	2.95
105	1	7	60	0	53331	109	2.65	0.32	1.12	1.02	6.08	5.44	2.57
106	1	1	0	0	53331	110	2.64	0.38	1.18	0.94	6.09	5.64	2.73
107	1	5	30	50	53331	116	1.35	0.24	1.09	0.73	6.18	5.39	6.29
108	1	8	60	50	53331	112	2.14	0.23	1.10	0.32	5.91	5.59	6.82
109	1	9	60	100	53331	107	1.01	0.33	1.17	0.77	6.11	5.48	8.26
201	2	5	30	50	53331	104	0.91	0.49	1.18	0.28	6.13	5.59	7.09
202	2	7	60	0	53331	106	2.55	0.86	1.26	0.69	6.16	5.23	4.22
203	2	2	0	50	53331	129	2.35	0.41	1.27	1.59	6.14	5.63	8.67
204	2	4	30	0	53331	91	1.33	0.68	1.19	1.27	6.64	5.63	2.67
205	2	6	30	100	53331	104	1.59	0.54	1.29	0.94	6.3	5.55	7.22
206	2	8	60	50	53331	124	0.87	0.58	1.28	0.69	5.21	4.79	7.57
207	2	1	0	0	53331	97	2.31	0.39	1.12	1.14	5.71	5.46	3.74
208	2	3	0	100	53331	86	2.35	0.46	1.32	1.10	6.13	5.72	8.51
209	2	9	60	100	53331	92	0.93	0.23	1.27	2.09	5.99	5.68	9.22
301	3	6	30	100	53331	99	2.49	0.47	1.48	1.92	6.89	5.72	7.30
302	3	7	60	0	53331	84	1.39	0.24	1.25	1.71	6.28	5.28	5.19
303	3	8	60	50	53331	88	2.52	0.41	1.27	2.65	6.42	5.27	6.38
304	3	5	30	50	53331	95	0.87	0.38	1.22	0.78	6.2	5.03	4.96
305	3	4	30	0	53331	92	2.63	0.45	1.29	1.51	6.09	5.42	4.32
306	3	3	0	100	53331	106	2.65	0.26	1.32	1.71	6.42	5.63	10.04
307	3	1	0	0	53331	91	0.90	0.31	1.40	1.26	6.14	5.27	3.84
308	3	9	60	100	53331	88	2.20	0.22	1.17	0.78	5.96	5.36	6.29
309	3	2	0	50	53331	93	2.20	0.19	1.25	1.67	6.2	5.37	5.79
401	4	1	0	0	53331	94	2.48	0.24	1.26	1.42	6.25	5.98	4.43
402	4	9	60	100	53331	99	2.60	0.33	1.31	2.00	6.07	5.59	5.16
403	4	5	30	50	53331	115	0.88	0.40	1.27	1.55	6.19	5.36	8.54
404	4	2	0	50	53331	86	1.33	0.40	1.24	1.71	5.79	5.72	7.57
405	4	7	60	0	53331	82	1.59	0.41	1.25	1.27	6.12	5.37	6.69
406	4	6	30	100	53331	103	0.87	0.40	1.27	1.10	6.24	5.05	3.13
407	4	3	0	100	53331	75	2.31	0.86	1.34	2.00	6.64	5.98	6.91
408	4	8	60	50	53331	99	2.35	0.33	1.22	1.63	6.49	5.58	7.53
409	4	4	30	0	53331	106	0.93	0.27	1.34	2.16	6.04	5.58	4.23

VITA

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