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BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES

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Inspiring Sustainable Growth

A dissertation submitted in partial fulfillment of the requirements for the award of the Master of Science Degree in Crop Science (Agronomy)

EFFECT OF COMPOST AMENDMENTS ON SOIL PHYSICO-CHEMICAL PROPERTIES, PLANT GROWTH AND EFFICIENT USE OF WATER, NITROGEN AND PHOSPHORUS IN MAIZE (ZEA MAYS L).

By

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May, 2022

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DECLARATION

I solemnly declare that this thesis represents my original work except where otherwise highlighted and has not been submitted for any award for a degree or of degree at any other universities.

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DEDICATION

This work is wholeheartedly dedicated to my late father-in-law (May his soul rest in peace); Mr. Keletshabe Nkosi Ndubo who has encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that what I have started. I also devote this work to my husband Ndubo Ndubo and my two boys Jaden Abang and Colby Isang who have been a source of inspiration and gave me strength when I thought of giving up.

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ABSTRACT

Compost is used across the world to sustain soil fertility and crop yield. This investigation consists of two experiments, which were conducted at BUAN greenhouses and farmers field in the Central District of Botswana in the period November 2018 to April 2019 involving maize (Zea mays.L). The experiments were carried out to test the hypotheses that soil amendments with compost as organic fertilizer improved soil physico-chemical properties, plant growth, WUE, NUE and PUE of maize under irrigated and drought stressed conditions. A completely randomized block design was used with the following treatments; **(1)** Soil + Urea (SU), **(2)** Soil + Urea + Compost (SUC), **(3**) Soil + Compost (SC), **(4**) and Soil (Control) replicated four times. The treatments for green-house trial comprised of two levels of irrigation, (W1= stressed at flowering stage, W2= irrigated). Data was collected on soil physico-chemical properties, plant growth, water use efficiency (WUE), nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE). The results showed that compost amendments significantly increased soil pH, EC, CEC, total carbon, total N, available P and cation exchange capacity (CEC). This study also revealed that WUE improved in stressed plants compared to irrigated plants; drought stressed treatments were more water use efficient than the irrigated treatments. PUE and NUE in SC and SUC were maintained higher than in control and SU under both conditions. The highest NUE 24.66kg/kg was exhibited for SUC treatments under irrigated condition as compared to the rest of the treatments. Moreover, SUC and SC recorded the highest PUE 210.35kg/kg and 141.89kg/kg under irrigated condition and 24.71kg/kg and 20.37/kg/kg under drought stressed condition respectively. In conclusion combination of compost and urea fertilizer significantly enhanced NUE, PUE and WUE in maize. These could decrease

the amount of fertilizer and water-use required for the sustainable production in maize under unstressed and stressed environment.

Key words: compost, water use efficiency, nitrogen use efficiency, phosphorus use efficiency, drought stress

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LIST OF SYMBOLS AND ABBREVIATION

A	Photosynthetic rate
ASS	Atomic Absorption Spectrophotometer
ATP	Adenosine Tri Phosphate
B	Boron
BUAN	Botswana University of Agriculture and Natural Resources
C	carbon
Ca	Calcium
CEC	Cation Exchange Capacity
CHL	Chlorophyll
Ci	Internal carbon dioxide gas
CO_2	Carbon dioxide
E	Transpiration rate
EC	Electrical Conductivity
FAOSTAT	Food and Agricultural Organization Statistics
Fe	Iron
gs	Stomatal conductance
H_2O_4	Hydrogen peroxide
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
ISPAAD	Integrated Support Programme for Arable Agriculture Development
K	Potassium
Kg	Kilogram
LSD	Least significant difference

MC	Moisture Content
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NEF	National Environment Fund
NUE	Nitrogen use efficiency
OC	Organic carbon
P	Phosphorus
PAR	Photosynthetic Active Radiation
pH	Potential of hydrogen
PUE	Phosphorus use efficiency
S	Sulphur
SAS	Statistical Analysis Software
SC	Soil + Compost
SOM	Soil Organic Matter
SU	Soil + Urea
SUC	Soil + Urea + Compost
TE	Transpiration Efficiency
WAE	Weeks After emergence
WUE	Water Use Efficiency
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Productivity in agriculture and crop growth are influenced by numerous biotic and abiotic stresses such as temperature, drought, pest and diseases, the soil quality (Thalmann and Santelia, 2017). Soil fertility and plant nutrition are critical aspects of cropping system and these include suitable supply of needed nutrients. Hence, the supply of these essential nutrient elements is considered as one of the basic needs to achieve the potential yield. Conversely, the land continues to undergo human-induced soil degradation and loss of productivity. Explicitly, low soil fertility is a threat to smallholder farmers' livelihood in Sub-Saharan Africa (SSA) (Nigussie *et al*., 2017). According to Havlin *et al.* (2014) as plants are removed from a field or soil sediments are transported offsite, nutrients in the soil are depleted. Natural soil nutrient supply depends on the soil̓s ability to buffer nutrient loss through crop removal. On the other hand, drought stress also restricts growth and photosynthetic activity (Graça *et al*., 2010; Jangpromma *et al.*, 2010; Barbosa *et al.*, 2015) which is responsible for the reduction in crop productivity (Ramesh, 2000; Zhao & Li, 2015). Poor management of plant growth resources such as nutrient and water management could leads to low use efficiency of resources due to poor productivity of losses through leaching.

Most soils when put under continuous cultivation decline in physico-chemical properties and leads to low crop yields after a few years of production. Management of soil fertility through use of chemical fertilizers is key to successful production of all agricultural produce. Chemical fertilizers have high nutrient content as compared to organic fertilizers and are rapidly taken up by plants. However, excess use of these chemical fertilizers can result in a number of complications, such as nutrient loss, surface water and groundwater contamination, soil acidification or basification, reductions in useful microbial communities and increased sensitivity to harmful insects (Chen, 2006). Additionally, Eurostat (2015) report stated that abundant use of fertilizers and pesticides also increases the risk that nutrients and pesticides run-off into surface and leach into groundwater. The acidity of the soil reduces crop phosphate intake, increases the concentration of harmful ions in the soil and hinders crop growth (Chandini *et al.,* 2019). The application of chemical fertilizer usually improves crop yield in the short-term (Zhang *et al*., 2009), but it barely maintains and even decreases SOC and has negative environmental impacts, such as acidification and nutrient loss (Cai *et al*., 2015).

Integration use of inorganic fertilizers with organic manures is a sustainable strategy for efficient nutrient usage which enhances efficiency of the chemical fertilizers while reducing nutrient losses (Schoebitz and Vidal, 2016). Combination of chemical fertilizer and compost to arable soils can lead to long-term increases in plant essential nutrients such as phosphorus (P), potassium (K), and magnesium (Mg) (Bulluck *et al*., 2002; Wortman e*t al.,* 2012a). The combined use of chemical and organic fertilizers is considered as a good method to sustain high crop yield and enhance soil organic carbon (SOC), but it is still unclear when and to what extent chemical fertilizers could be replaced by organic fertilizers. According to Wang *et al*. (2016) among the types of organic fertilizer applications, manure amendments are favored for increasing SOC stock and supplying nutrients to crops because they have higher SOC sequestration efficiency. Organic fertilizers application is a widely accepted strategy to sustain crop yield and SOC stock, and has significant effects on climate change mitigation (Lu *et al*. 2015) and also soil fertility sustainability (Liu *et al.* 2014).

In semi-arid lands composted organic material can be used as a source of important nutrients for sustainable crop productivity (Amanullah *et al*., 2015). In Botswana a large proportion of soils are characterized by high sand content and low organic matter content; hence, their management is very critical. Basically, sandy soils are of low productivity due to poor water holding capacity, low cation exchange capacity and low nutrient holding capacity. The productivity of these soils nevertheless, could be improved by compost amendments to sustain crop production. The use of compost as fertilizer has multiple benefits such as an increase in organic C content and microbial activity (Scotti *et al*., 2015), a greater concentration of plant nutrients like N, P K and Mg, and a root reinforcement (Donn *et al*., 2014). Soil structure can also be improved by binding between soil organic matter and clay particles by means of cation bridges and through stimulation of microbial activity and root growth (Farrell and Jones, 2009; Gao *et al*., 2010). Good soil structure favors air and water transfer in soils, seed germination and root growth and reduction in erosion. In a study Chakraborty *et al.* (2011) reported that organic amendments, once added to the soil, favors the growth and diversity of microbial communities, highlighting a strong correlation between soil biological fertility and soil organic C content. Studies had provided evidence that the use of compost as organic amendment positively affects soil fertility in terms of biological and enzymatic activities (Thangarajan *et al.*, 2013), in particular under intensive farming systems (Scotti *et al.*, 2015). The use of compost can affect soil microbial diversity, as reported by Zaccardelli *et al.* (2013a) who showed a clear positive effect on the number of spore-forming bacteria, with an increase directly correlated with the dose of compost. Successful use of compost relies on evaluating the soil to be amended followed by an evaluation of the compost and its properties. In general, organic soil amendments are often promoted as a tool for building soil quality through improved chemical, physical, and biological properties.

1.2 The maize crop and its ecological physiology.

Maize (Zea mays L.) is an important cereal crop grown all over the world under a diverse type of climate. Rainfall of between 500 to 900mm is sufficient to grow a good crop of maize. However, in Botswana maize is grown under marginal rainfall conditions of 200 to 600mm which often exposes the crop to drought stress. Maize is a fast growing crop that requires abundant moisture. A significant reduction in maize yield due to water deficit even at high doses of nitrogen has been reported (Moser *et al.,* 2006). Management of irrigation water and nitrogen is crucial in order to improve maize productivity with reduced pollution risks (Gheysari *et al.*, 2009). Among the major cereal crops, maize is the only monoecious plant bearing unisexual flowers. The male inflorescence or tassel develops from the shoot apical meristem at the top of the plant, whereas the female inflorescence or ear develops from lateral meristems in the axil of leaves. These spatial arrangement of the flowers facilitates both selfing and crossing pollination (Morris, 2002).

Past studies indicate that for better performance, maize needs a pH of 5.8 - 7.0 (Albrecht *et al*., 2005; Mallarino, 2011; Crouse & Denny, 2015). Kai *et al*. (2012) noted that crop performance is affected indirectly by low soil pH from aluminum and manganese toxicity which resulted from overly acidic conditions of the soil. Good sprouting of this crop is attained at soil temperature of 20-22°C. Optimum range of temperature for better crop growth and yield realization is 25–35°C (Zaidi *et al*., 2017). Soil moisture of 60-70% field water capacity is most favorable for maize plant. Furthermore, extended low temperature less 5°C severally affects the crop. Being day neutral, maize crop can be cultivated throughout the year which leads to high yield levels in a short period of time.

1.3 Constraints to maize production.

Previous studies have observed several challenges contributing to reduced maize productivity, such as, combined effects of abiotic and biotic stresses, highly variable environmental conditions, use of inappropriate maize varieties and limited resources (Fanadzo *et al.*, 2009; Jacobson, 2013; Tandzi *et al.*, 2015). Soil moisture retention is low in many of Botswana's soils. This is also intensified by soil caking and layering resulting from inferior tilling technologies (Sustainable Agriculture and Rural Development, 2007).

Nitrogen is a determinant nutrient for plant growth and a good supply for the plant is also important for the uptake of other nutrients including potassium, phosphorous (Bell, 2016). It is also the essential element most frequently scarce in soils around the world. It is a key nutrient for obtaining maximum yield and quality, but also one of the most difficult element to optimize. Nitrogen encourages leaf growth and an inadequate supply means smaller leaves, reduced photosynthesis, and less total yield and protein. If nitrogen supply is too high, then excess leaf will be formed at the expense of grain, starch content will be reduced and yield may also suffer. Too much nitrogen may also delay maturity and result in lodged crops. The choices of suitable forms of fertilizer for the proper growth of the plant are governed by local natural conditions and variations in soil and climate with regard to their suitability for maize cultivation. Excessive N leaching from fields is a leading source for degradation of water resources (Ewing and Runck, 2015) while N fertilizer inputs are also linked to increased nitrous oxide (N_2O) emissions (USEPA, 2014).

1.4 Maize contribution to cereal trend production in Botswana.

Cereal production in Botswana is based on rain-fed farming and nearly 70% of Batswana are resident in rural areas, where agro-pastoralism is still regarded as the dominant livelihood system (Statistics Botswana, 2012). Bio-physical factors such as low and unreliable rainfall, recurrent droughts, very high summer temperatures and poor sandy soils characterize crop production environment in Botswana. The majority of traditional farming households in the country practice arable production with low factor endowment, which cause few of these farmers to utilize soil fertility enhancing strategies. The hostile environment and lack of fertilizer use lead to low cereal crop productivity of which maize is the most affected. Historical data **(**1979-2015) (Statistics Botswana, 2015) shows that arable crop sub-sector has the potential to produce sorghum yield exceeding 600kg/ha of cereal grain as was the case in 1995 (Figure 1.2). However, maize productivity hardly exceeds 200 kg/ha and this is evidence that it is vulnerable to unfavorable environment and poor nutrient management.

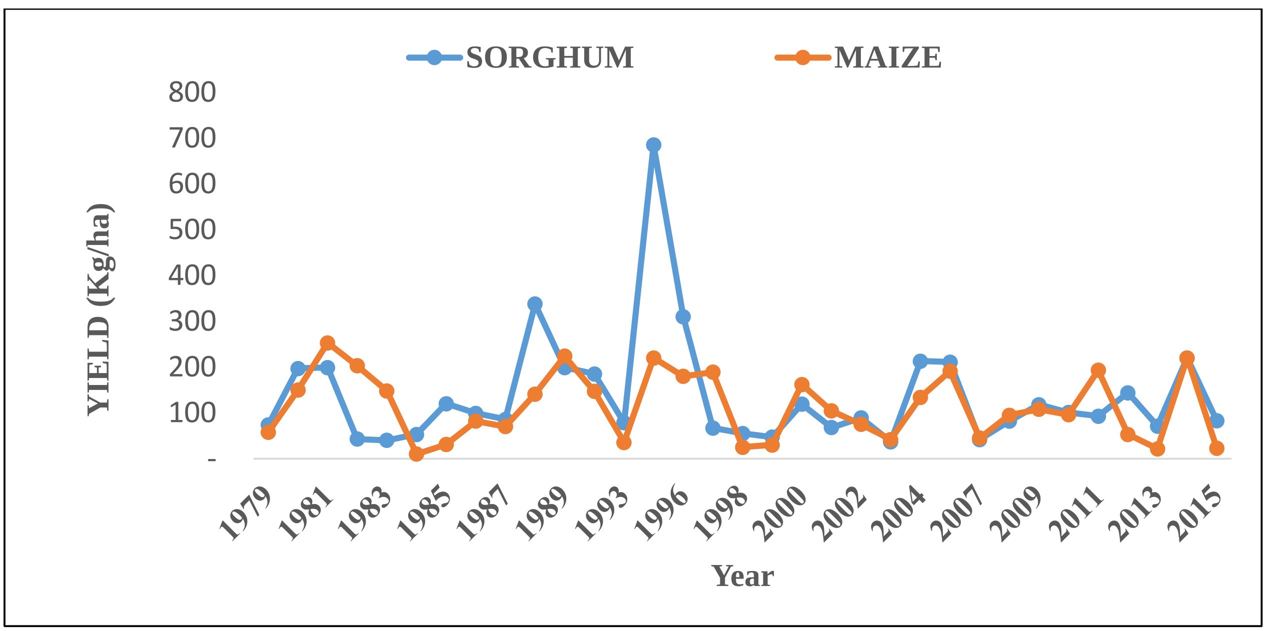


Figure 1.2: Historical Maize and sorghum production trends (1979-2015): Source (Statistics Botswana)

1.5 Justification of study

Botswana soils are characterized by high sand content and these soils are mostly considered as very delicate with respect to agricultural production due to their very low nutrients and organic matter content (Boul *et al.,* 2003). Most of Batswana farmers are small scale holders who rely on dry-land production thus depending on rainfall as a sole source of water, hence this system of production exposes plants to drought and nutrient stress which results in low productivity. With the least rain water and the low soil nutrient in Botswana, this research focused on how the challenges of drought stress and low soil fertility can be improved by compost to increase productivity with emphasis on some of the key resources namely; water, nitrogen and phosphorus use efficiency.

In agricultural production, water and nutrients plays a major part for plant development, therefore addressing the problem of soil nutrient deficiency farmers are currently issued with free chemical fertilizers by the Ministry of Agricultural Development and Food Security through Integrated Support Programme for Arable Agriculture Development (ISPAAD) to solve the challenges of low agricultural productivity caused by poor soil fertility. However, continuous use of these chemical fertilizers is known to be a source of some greenhouse gases and pollution of underground water. The cost of these chemical fertilizers to the government of Botswana and the potential environmental risk posed by their overuse have awaken the interest in using compost in crop production in order to mitigate climate change effects and with the least rain water and the low soil nutrient in Botswana, this research focused on how the challenges of drought stress and low soil fertility can be improved by compost to intensify desirable use of resources (Water and nutrients) with the aim of maximizing available soil moisture and increasing yields.

Combining compost and chemical fertilizers will ensure that the problems associated with the use of either compost or inorganic fertilizers are greatly reduced as the combination of both fertilizers complement each other. The combined application of compost and chemical fertilizers is also widely recognized as a way of increasing yield and improving productivity of the soil (Kassahun and Mekonnen, 2012).

1.6 General objective

- To investigate the effect of compost amendments on water, nitrogen and phosphorus use efficiency of maize.

1.7 Specific objectives

- To determine the effect of compost amendments on soil physico-chemical properties under rain-fed, water deficit and irrigated conditions.
- To determine the influence of compost amendments on maize plant growth under water deficit and irrigated conditions.
- To determine the effect of compost amendments on maize WUE under water deficit and full irrigated conditions.
- To determine the effect of compost amendments on NUE and PUE under water deficit and irrigated conditions.

1.8 Hypotheses

- ***1) Null hypothesis:*** Amendment of soil with compost will not affect maize WUE under water deficit and irrigated conditions.
- ***Alternative hypothesis:*** Amendment of soil with **c**ompost will affect maize WUE under water deficit and irrigated conditions.

- ***2) Null hypothesis:*** Amendment of soil with compost will not affect maize NUE and PUE under water deficit and irrigated conditions.
- ***Alternative hypothesis***: Amendment of soil with compost will affect maize NUE and PUE under water deficit and irrigated conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Nutrients and water requirements of maize crop.

Efficient use of water and nutrients by crops demands for reviewed or new agricultural crop management practices to sustain agricultural production (Shrestha *et al*., 2010). The term "nutrient uptake" when applied to crops refers to the process by which plant roots take up nutrients present in soil solution and such nutrients subsequently distributed to aerial portions of the plant. The process is affected mainly by environmental conditions, management practices, the concentration of nutrients and the form in which nutrients are present in the soil. Nutrient use efficiency is described as the ability of a plant to utilize soil available nutrients to result in measurable yield or yield parameters such as dry matter, fruit or grain production (Hati *et al*., 2006).

Nitrogen and phosphorus are the two most limiting elements of crop production. According to Liu *et al*. (2015) maize plant is considered as a greedily plant to fertilization, particularly to nitrogen when irrigation water is available. The extent of N losses is also dependent on the form of N applied. Nitrate, for instance, is mostly present in soil solution given its low adsorption to soil particles (Marchi *et al.*, 2016). Hence, nitrate can be expected to leach below the root zone in furrow irrigation during periods of excess soil moisture conditions or by preferential flow, given its tendency to be transported by convection. Soil P deficiency is also one of the major factors limiting crop yields worldwide. Although required by plants in a smaller quantity compared with other primary macronutrients, the inadequate supply of P results in severe limitations in plant growth. Phosphorus use efficiency (PUE) on field treated with conventional chemical fertilizers has been reported low ranging between 5 – 40 % for many tropical soils (Syers *et al*., 2008).

Water is considered as a major factor in nutrient availability to plants as it is the vehicle through which nutrients move through soil to access plant roots for uptake. Increasing global scarcity of water will also impact the way in which N fertilizer is accessed by plants and profoundly compromise crop productivity (Swarbreck *et al.*, 2019). As water is a limiting resource in many regions of the world, the improvement of water-use efficiency (WUE) by crops is critical to maintaining food security. It is clear that improvement of WUE in crops must be accompanied by agronomic strategies to reduce water requirements in agriculture. Du *et al*, (2015) reported that mild water deficit does not lead to serious losses in yield, even increases production and is beneficial to improve WUE. In water-limited environments, plants should minimize water loss while maximizing carbon uptake to optimize their water-use strategies (Galiano *et al*., 2011; Adams *et al*., 2013; Mitchell *et al.*, 2013). For this reason, water use efficiency (WUE) is an important indicator of plant adaptability and sustainability, especially under drought stress. Maize has been found to have high water use efficiency when compared to other crops as well as being highly nutrient efficient because it produces high biomass in linear response to nutrient availability without excessive evapotranspiration (Ogola *et al*., 2002). Under drought stressed environments, WUEg response to N supply will be closely associated with the timing and intensity of the water and N deficiencies. However, studies found that appropriate moisture regulation increased the WUE of maize and increased its ability to resist drought (Li *et al*., 2018). One of the most frequently used indices to evaluate the response of crops to a specific climatic condition and water supply is water use efficiency (WUE).

2.2 Growth responses to drought stress in maize.

FAOSTAT (2014) has documented that almost 80% of the world's agricultural production is under rain-fed conditions and it provides 62% of the staple foods. However, the issue of water is crucial for environmental sustainability of agriculture, because 60% of agriculture is located in semi-arid areas where regular water applications are necessary to complete the growth cycle of crops (Bhattacharya, 2019). According to Hussain *et al.* (2019), world maize yield and production are projected to decline by 15–20% per year due to heat and drought conditions, with these two factors becoming major threats to this crop. Maize is an extremely water-sensitive crop and most of the maize-grown areas are rain-fed. Maize susceptibility to drought is due to the plant's water requirement for cell elongation and its' inability to delay vegetative growth. Drought is considered as one of the major environmental stresses that limit plant growth and consequently, crop-yield. It causes a broad range of growth, photosynthetic, metabolic, and ultrastructural variations in plants (Cui *et al.*, 2017). Drought affects various morpho-physiological processes including plant biomass, root length, shoot length, photosynthesis, water use efficiency (WUE) and leaf water content (Egilla *et al.*, 2005; Abdul *et al*., 2008). Research showed that plants respond to water deficit and adapt to drought conditions through various physiological and biochemical changes including phenological modifications (Basu *et al*., 2016). A study by Anjum *et al.* (2011a) showed that drought stress in maize led to considerable decline in net photosynthesis (33.22%), transpiration rate (37.84%), stomatal conductance (25.54%), water use efficiency (50.87%), intrinsic water use efficiency (11.58%) and intercellular CO2 (5.86%) as compared to well water (WW) control.

Drought stress may occur during the stage of vegetative or generative transition in the shoot apical meristem depending on the cereal species and on the geographical location of plant cultivation. The appropriate corresponding pattern of inflorescence development and the time of flowering to the temporal variation in water availability is recognized as one of the most important traits conferring adaptation to drought. Maize has different responses to water deficit depending on developmental stages (Cakir, 2004). There are indications that maize is relatively less sensitive to water stress when this occurs during early vegetative growth stages, given the relatively reduced crop evapotranspiration (Steduto *et al.*, 2012). Drought stress that occur during reproductive phase, may lead to embryo abortion and pollen sterility in some cereal species (e.g., rice, maize) (Araus *et al.*, 2011; Fischer *et al*., 2011), signifying that the effect of drought on yield during this period could not be returned by adding water afterwards therefore, the length of the stress period is also an important factor. Soil water depletion to the wilting percentage for two (2) days during the tasseling or pollination period can result in as much as a 22% decrease in yield, while a six (6) - eight (8) days period of depletion can cause a yield reduction of about 50%. At the onset of drought, maize plants of all ages will wilt in the afternoon and recover turgidity at night. The stomata of maize plants when exposed to severe drought for three (3) or four (4) days resume much of their apparent normal behavior after one or two day recovery period. But, severe drought over longer periods of one week or more produces marked changes in stomatal behavior and they never again seem to be able to open fully**.** Independently from the mechanism by which stomata close, it has been proposed that stomatal regulation avoids excessive drop in leaf water potential by responding to nonlinearities in the relationship between transpiration rate and leaf water potential (Sperry and Love, 2015; Sperry *et al.*, 2016).

Inadequate available soil water declines the metabolic activity of maize, lessens its biomass accumulation, and decreases its photosynthetic rate by reducing the chlorophyll content in leaves, eventually leading to a decrease in maize yield (Zhang *et al*., 2009; Bu *et al*., 2010). Drought stress at tasseling does not only hinders the plant's ability to flower and shed pollen, but also can greatly affect the viability of maize pollen, especially when the drought is accompanied by high temperatures as is usually the case. Such stress increases the time required for pollination and delays silking. The result is that at times all the pollen may be shed before the silks emerge. Water stress limits maize growth and yield mainly due to reductions in its carbon-water balance (Zhang *et al.,* 2018)], which is largely dependent on photosynthesis (Campos *et al*., 2014).

Plant physiological processes are highly sensitive to water stress, particularly those that are related to the plant organ water state (Zhang *et al*., 2010). Generally, crop photosynthetic characteristics have been taken as critical indicators of plant growth since they are directly related to net productivity (Huang *et al*., 2020). Drought stress from booting stage through approximately ten (10) days after anthesis will severely affect yield. At the seedling stage, drought stress is likely to damage secondary root development. In general, the combination of drought and high day time temperatures reduces the photosynthetic efficiency, stomatal conductance, leaf area, water use efficiency (WUE), and yield of plants (Sattar *et al*., 2020).

2.3 Physiological responses of maize under drought stress.

Water deficit limits crop productivity more severely than other environmental factors apart from soil fertility. The severity of drought is unpredictable as it depends on several factors such as occurrence and distribution of rainfall, evaporative demands and moisture storing capacity of soils (Abdulai, 2005). According to Vadez *et al*. (2011) genotypic variation in crop response to drought depends on agronomic, environmental and genetic factors. The physiological responses of maize plants to drought and heat can be classified into three different mechanisms: escape, avoidance, and tolerance. The photosynthetic and gas exchange responses are the most sensitive to water deficits and maintaining relatively high photosynthetic activity levels may enhance plant drought tolerance. In maize, the combination of drought and heat reduces rate, stomatal conductance, leaf area, and WUE (Sehgal *et al.,* 2017). According to Huo *et al.* (2016) photosynthetic systems are susceptible to damage during responses to water deficit stress. Zhao *et al*. (2016) also reported that maize crops are extremely sensitive to heat and drought stress. Maize seedlings growing under water stress conditions exhibit several important physiological responses, including decreased cell turgor (Chen *et al.,* 2015; Gall *et al.,* 2015), leaf rolling (Kadioglu *et al* ., 2012), inhibited CO2 exchange and decreased photosynthetic efficiency and chlorophyll contents (Mao *et al*., 2015; Bunce *et al* ., 2010). It is also believed that CO_2 assimilation by leaves is mainly reduced because of stomata closure in drought stress conditions (Farooq *et al.,* 2009). The reproductive stage is more sensitive to the combination of drought and heat than the vegetative stages (Obata *et al*., 2015; Sehgal *et al.,* 2017). The reproductive processes most susceptible to the combination of heat and drought stress are pollen and stigma viability, pollen tube growth, early embryo development, flowering and seed filling, and number of kernels (Zandalinas *et al.*, 2017; Lamaoui *et al.,* 2018; Sehgal *et al.,*2019).

2.4 Water use efficiency and its relation to drought resistance in maize.

Crop plants require sufficient water if they are to grow to their optimum levels and water consumption varies greatly throughout the growing season depending on the environmental conditions they grow. WUE has been defined as the ratio of instantaneous photosynthesis (*A*) to transpiration (*T*) (Sun *et al.* 2015), which is mostly controlled by stomata opening and closure (Huang *et al*. 2017a). Intrinsic water use efficiency (WUEi) has also been utilized to reflect the biochemical characteristics of plants based on photosynthesis (*A*) and stomata conductance (*g*) (Beer *et al.* 2009; McCarthy *et al*. 2011).

Photosynthesis in C4 plants is more sensitive to drought periods due to stomatal closure and the reduction in the activity of photosynthetic enzymes compared to C3 plants (Ghannoum, 2009; Lipiec *et al.,* 2013). Under thermal stress, photosynthesis in C4 plants shows a greater tolerance than in plants with C3 metabolism, associated with the accumulation of oxaloacetic acid within the bundle sheath cells. Maize is a C4 plant, which confers potentially more efficient use of CO_2, solar radiation, water and N in photosynthesis than C3 crops. Species with the C4 photosynthetic pathway have evolved biochemical CO_2 concentrating mechanisms that allow Rubisco to function in a high CO_2 environment. The C4 biochemical pathway, in which the first products of photosynthesis are C4 carboxylic acids, and specific bundle sheath anatomy of leaves enable higher rates of photosynthesis than the C3 biochemical pathway. As C4 plants frequently, but not always, have lower stomatal conductance, the Transpiration Efficiency (TE) of C4 species is considerably greater than that of C3 species when directly compared in the same environment. This increases both nitrogen and WUE compared to C3 species. It is well accepted that crops differ in WUE abilities. Several other studies pointed that cereals tend to have higher WUE than oilseed crops (Norton and Waschsmann, 2006; Sadras and Mcdonald, 2012). Water use efficiency (WUE) of maize is approximately double that of C3 crops grown at the same sites. Crops are drought-sensitive at certain growth stages (Wang *et al*. 2011), whereas drought-tolerant at other phenological stages. Maintenance of water uptake by the development of deep roots into a wet profile will maintain the assimilation rate of leaves and there high WUE.

The soil system is viewed as the storage site for liquid water accessible to the plant through the root system. Soil texture and depth of the soil system determines the total water supply available to the plant. Another very important factor affecting soil water is soil structure which measures the type and degree of aggregation among soil particles defining the texture. Soil aggregates affect the ratio of macro-pores to micro-pores. This ratio affects infiltration and drainage of water and movement of gases in the soil system, therefore changing the soil nutrient status influences water use efficiency as a result of the nutrient status of the soil that facilitate plant growth and ultimately the amount of biomass produced per unit of water consumed. Application of fertilizers promotes root growth which extracts soil moisture from deeper layers. It is known that proper nutrient levels in the soil will lead to increased crop growth and productivity and as such WUE (Yada, 2011).

2.5 Nitrogen use efficiency and its relationship with WUE under drought stress conditions.

As much as water is a limiting factor in crop production, nutrition also has a greater influence on the final yield. Shortage of N constrains shoot and root growth, which reduces plant water and nutrient uptake capacity (Salvagiotti *et al*., 2008; Setiyono *et al*., 2010). Among all the plant nutrients essential for crop growth, nitrogen is the most limiting crop nutrient for most non-legume production systems (Zotarelli *et al*., 2007) and thus the most limiting in crop production. Nitrogen use efficiency (NUE) is the degree to which N is used by plants, and specifically refers to the efficiency by which crops produce biomass or harvested product from a unit of acquired N (Bell, 2014).

From both a physiological and agronomic point of view, NUE is the result of two main biological processes: N uptake efficiency (NUpE) which corresponds to the amount of N taken up per unit of available N, and N utilization efficiency (NUtE) which corresponds to the increase in biomass or yield per unit of N taken up. During the plant developmental cycle, a number of complex physiological processes are involved in the control of plant NUE notably N uptake, N assimilation and N translocation. In many arid and semi-arid regions, WUE and NUE are often low due to low crop yields, degraded soil fertility and low and erratic water and N inputs (Rockstrom *et al*., 2010; Sanchez, 2010; Rockstrom and Falkenmark, 2015). It was reported that in many developed and rapidly developing countries, WUE and NUE are also rather low because of over-application and poor management (Sutton *et al.,* 2013). Cereals in general and maize in particular, need to remobilize the N accumulated in proteins in vegetative tissues and at the same time take up and assimilate N after anthesis, in order to ensure storage protein deposition in the grain.

A study Gebreyesus (2012) reported that soil moisture without soil fertility or fertility without soil moisture is less effective for production increment in the semi- arid areas. Nitrogen and water are directly related as nitrogen requires water to be fully dissolved in the soil for easy uptake by the plant roots. Crops may not be able to use nitrogen (N) efficiently if water is a limiting factor for growth and production. A limited supply of both water and N leads to a distorted crop development and growth or to low crop yields. Effects can be large when the supply of both is limited. Yared *et al.* (2010) also documented that reduction in low soil moisture can reduce nutrient uptake by roots and prompt nutrient deficiency by reducing the flow of nutrients from the soil to the roots, creating restrained transpiration rates and impairing active transport and membrane permeability.

Soil available water and N content are some of the major limiting factors for crop production (Lenssen *et al*., 2007; Sainju *et al*., 2009). Precipitation, being the major source of available water for dryland crops, needs to be used efficiently to sustain yield. The increasing use of inorganic fertilizer and neglect of organic fertilizer as a valuable source of nutrients have contributed to nutrient imbalance, low fertilizer use efficiency, deterioration in soil quality, nitrate leaching, soil acidification and carbon (C) loss which seriously limit crop productivity and soil nutrients. Most importantly, the significant increases in WUE under organic fertilizer treatment is not a function of higher water uptake. An integrated approach, combing application of compost with an application of artificial fertilizer is a good strategy for sustainable crop production (Gete *et al.*, 2010). Soheil *et al.* (2012) determined the effects of Municipal Waste Compost (MWC) on soil chemical properties and corn plant responses in pot experiment. They found that the amount of available N, P and K and micronutrient/heavy-metal concentrations in soil increased as the result of waste compost application Addition of N and P fertilizer enhances root development, which improves the supply of other nutrients and water to the growing parts of the plants, resulting in an increased photosynthetic area and thereby more dry matter accumulation. This could ultimately increase WUE in crops such as maize. Recent studies have demonstrated that there are large differences in maize lines and hybrids in their ability to grow and yield well on soils with low mineral nutrient availability, which depends on both N-uptake efficiency and N-utilization efficiency (Hirel and Gallais, 2011). The effects of fertilizers on wheat yield and water use efficiency (WUE) have been intensively studied. Generally, the application of inorganic fertilizer can increase crop yield by increasing biomass accumulation, but greater biomass accumulation increases transpirational leaf area, creating excessive transpiration and water loss from the crop canopy, which in turn cause severe soil water depletion during the wheat-growing season in semi-arid regions (Chen *et al*., 2015). Management of nutrient supply is a strategy to improve WUE.

2.6 Phosphorus use efficiency and its relationship with water use efficiency.

Phosphorus (P) is the most important essential nutrient for cereal production and animals (Wang *et al*., 2017). It is known to be the second most limiting nutrient in crop production after nitrogen. It is a key element required for normal plant development, but its low mobility in soil results in poor uptake by plants, which consequently inhibits growth and metabolism. It is involved in several key plant functions including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from generation after generation. The majority of soil types, including fertile soils, have low available phosphorus, because the rate of absorption in the rhizosphere exceeds the rate of its replenishment in soil solution (Suriyagoda *et al*., 2011). According to Conde *et al*. (2014) low P availability is one of the major factors limiting crop production in acidic soils.

Application of water within a certain range and phosphorus can effectively improve the absorption, transformation, and utilization of fertilizers by crops. Studies showed that appropriate fertilization can reduce the negative effects of soil water deficiency on crop growth and development to a certain degree (Yang, Guo, Wang, Yang, & Yang, 2012) and can also increase the phosphorus concentration in plants (Gu *et al.*, 2018) with increased phosphorus uptake. Schärer *et al*. (2010) also noted that appropriate management of water and fertilizer can not only increase crop yield and reduce irrigation and phosphorus application but can also reduce total phosphorus and increase available phosphorus in soil. The use of P fertilizer reduces its deficiency in soil, increases the stress-tolerating ability of plants (Cortina *et al*., 2013) and results in adjustments of physiological, morphological, and biochemical processes that increase plant growth (dos Santos *et al*., 2004; Jones *et al*., 2005; Campbell and Sage, 2006; Faustino *et al*., 2013; Liu *et al*., 2015). In addition, anions as phosphorus showed an increased solubility subsequently to organic material application (Zaccardelli *et al.*, 2013b; Scotti *et al.*, 2015). P use efficiency (PUE) for cereal production in the world is too low, varying between 15 and 30% (Dhillon *et al.*, 2017). Phosphorus use efficiency in maize fields is critically important, since this nutrient constitutes one of the most limiting factors to production. There are numerous definitions for PUE (White *et al*., 2005; Hammond *et al*., 2009; Rose and Wissuwa, 2012). Phosphorus (P) uptake efficiency refers to the plants ability to obtain Pi from the soil, and P utilization efficiency to the capacity for biomass production using the P absorbed (Wang *et al*., 2010). Increasing PUE can be achieved either by increasing uptake capacity or by optimizing its utilization (Shenoy and Kalagudi, 2005; Parentoni and Junior, 2008). Previous studies suggest that phosphorus contributes for the extension of root system and P deficiency will increase drought stress (Cramer *et al*., 2009; Sardans and Penuelas, 2012). Despite the importance of P in plant productivity, relatively few studies have assessed its effects on plant physiological and ecological processes under drought stress (dos Santos *et al*., 2006; Naeem and Khan, 2009; Fleisher *et al*., 2012; Jin *et al*., 2015; Liu *et al*., 2015).

The combination of water and fertilizer can effectively improve the water-use efficiency and phosphorus-use efficiency of alfalfa (Lenssen *et al*., 2010), which is beneficial for reducing the loss of agricultural water in the field and the excessive use of phosphate fertilizers. Water and wind erosion are significant factors that contribute to low world PUE and represent an economic and environmental risk. When soil is subjected to erosion, P is also lost, further reducing crop productivity and ultimately, PUE (Schröder *et al*., 2011). An assessment of soil P loss due to erosion was reported by Liu *et al*. (2008) who suggested that 13, 8, and 3 kg P ha are lost on an annual basis from arable land, overgrazed and normal pastures, respectively. According to Oyeyiola and Omueti. (2016) composted plant residues and animal waste materials mixed with rock phosphate have been demonstrated to enhance P availability and P use efficiency compared to rock phosphate alone on severely acid soils.

2.7 Soil nutrient management for improving water use efficiency in crop production.

The best management practices to pursuit nutrient use efficiency include applying fertilizers according to plant needs and placed correctly to maximize uptake. Fertilizer does not only enhances plant growth but also stimulates root growth to allow water uptake from deeper soil layers, particularly during drought spells. The use appropriate types and quantities of nutrients from mineral and organic sources is an essential practice for improving nutrient efficiency.

Most literature in agricultural fields have reported that the mixed use of chemical fertilizer and organic fertilizers decreases the damage that can be induced by chemical fertilizers and improved crop productivity. Studies also have indicated that the combination of organic and inorganic fertilizers ensure greater synchrony between nutrient release and plant uptake and therefore increase crop yield (Mugwe *et al.,* 2009; Omotayo & Chukwuka, 2009). Poor soil fertility limits the ability of plants to efficiently use water (Bossio *et al*., 2008). According to Mugwe *et al.* (2009), maize grown in soil enriched with organic materials and inorganic fertilizer had higher grain yield compared to the recommended rate of inorganic fertilizer. The combination is a result of enhanced nutrient use efficiency, improved synchronization of nutrient release and uptake by the crop, as well as reduced acidity and a more balanced supply of nutrients. Moreover, applying organic materials over several seasons results in increased yields, because the tannin and lignin content slows their decomposition and has a long-term effect on nutrient availability.

A number of studies indicated that the presence of organic matter in the soil is fundamental in maintaining the soil fertility and decreasing nutrient losses. Thus, compost is a good organic fertilizer as it contains nutrients as well as organic matter. Organic matter has number of important roles to play in soils, both in their physical structure and as a medium for biological activity. Many recent studies highlight the importance of soil organic matter (OM) with regard to climate change (Adewopo *et al*. 2014; Lin, 2014; Amundson *et al*. 2015; Baveye, 2015). Studies have also shown that compost input could increase the soil water-holding capacity (Fan *et al*., 2005, and Wang *et al.,* 2011) and successfully match N availability with crop uptake thereby improving yield and WUE.

Application of compost increases soil physical fertility, mainly by improving aggregate stability, decreasing soil bulk density and increasing soil pore volume (Leroy *et al*., 2007; Olabode *et al*., 2007; Manivannan *et al*., 2009). Another study compared three different soil types (two different loamy coarse sands and a coarse sandy loam) with sludge compost application of 50% v/v (Somerville *et al.*, 2018). All three soils had a reduced bulk density at both 3 (15–26% reduced) and 15 (14–25% reduced) months post compost application. Basically, it provides nutrients to the soil, improves its water holding capacity, and helps the soil to maintain good tilth and thereby better aeration for germinating seeds and plant root development (Edwards and Hailu, 2011). According to Van Camp *et al*. (2004) composting helps to optimize nutrient management and the land application of compost may contribute to combat soil organic matter decline and soil erosion.

Many experiments have shown that compost improves the aggregate strength of soils. This means that the soil is more resistant to compaction and roots can penetrate more easily to for reach water and nutrients absorption. Liu *et al*. (2013) found that organic fertilizer increased the soil water-holding capacity by increasing the percentage of macro-aggregates. Furthermore, compost addition increases soil organic matter (SOM) content, which enhances aggregation and stability, thereby ameliorating soil structure (Diacono and Montemurro, 2010). Compost contains organic molecules (chelators) that bind metal cations such as Fe, Cu, Zn and Mn, and maintaining them in a soluble state (Van Schoor, 2009). Chelate formation is important in the soil because it reduces the toxicity of plant nutrients and also minimizes unnecessary losses of nutrients through leaching, thereby making them available exactly when needed. In general compost has the ability to preserve nutrients from leaching away through water. Compost has two main effects on soils, particularly in nutrient poor soils: replenish soil organic matter and supply plant nutrients therefore addition of organic matter in the soil is a well-known practice to increase crop yields. Aziz *et al.* (2010) reported an influence of compost on plant growth. In maize these include; stem length, number of leaves and leaf length were significantly influenced by the application of compost at different concentrations.

A study on maize (Zea mays L.) in acidic soil by Murmu *et al.* (2013) found that organic manure increases crop productivity, nitrogen utilization efficiency, and soil health compared to chemical fertilizer. Compost contains significant amounts of valuable plant nutrients including N, P, K, Ca, Mg and S as well as a variety of essential trace elements (Agegnehu *et al*., 2014). Compost helps in retaining soil moisture, slow release of nutrients to crops and can lead to long-term yield increases. Importantly, using compost made from recycled resources is sustainable and can increase soil organic matter and water absorbing and holding capacity.

Cation exchange capacity (CEC) is one of the most important indicators for evaluating soil fertility, more specifically for nutrient retention. Low CEC soils are more susceptible to cation nutrient loss through leaching. This enables the soil to hold nutrients such as potassium, which would otherwise leach beyond rooting depth Mohammed *et al.* (2004); Agegnehu *et al.* (2014); proved that compost amendment resulted in an increase of CEC due to input of stabilized organic matter being rich in functional groups into soil.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Experimental sites

Two experiments were carried out under open field (Experiment I) and controlled environment in the greenhouse (Experiment II) during the 2018/19 growing season.

3.1.1 Experiment I

This open field experiment was conducted in Matlhakola village in the Central District of Botswana in the period of November-April 2018/19 on a farmer's field. The site is located at latitude 22° 33' 0" S and longitude 27° 8' 0" E. The climate is considered to be a local steppe climate with an average annual rainfall of 427 mm. The average temperature is 20.1 °C. Soils at this experimental site are sandy and considered poor in fertility status. The dominant soils in this area are classified as Orthic Luvisols (Figure 3.1). Classification of soil at experimental plot in Matlhakola site is presented in Table 3.1. The experimental plot was 32m by 100m occupying a total area of 3200m^2 (0.32ha). The area was cultivated to clear it of weed and incorporate crop stubble from previous season crop.

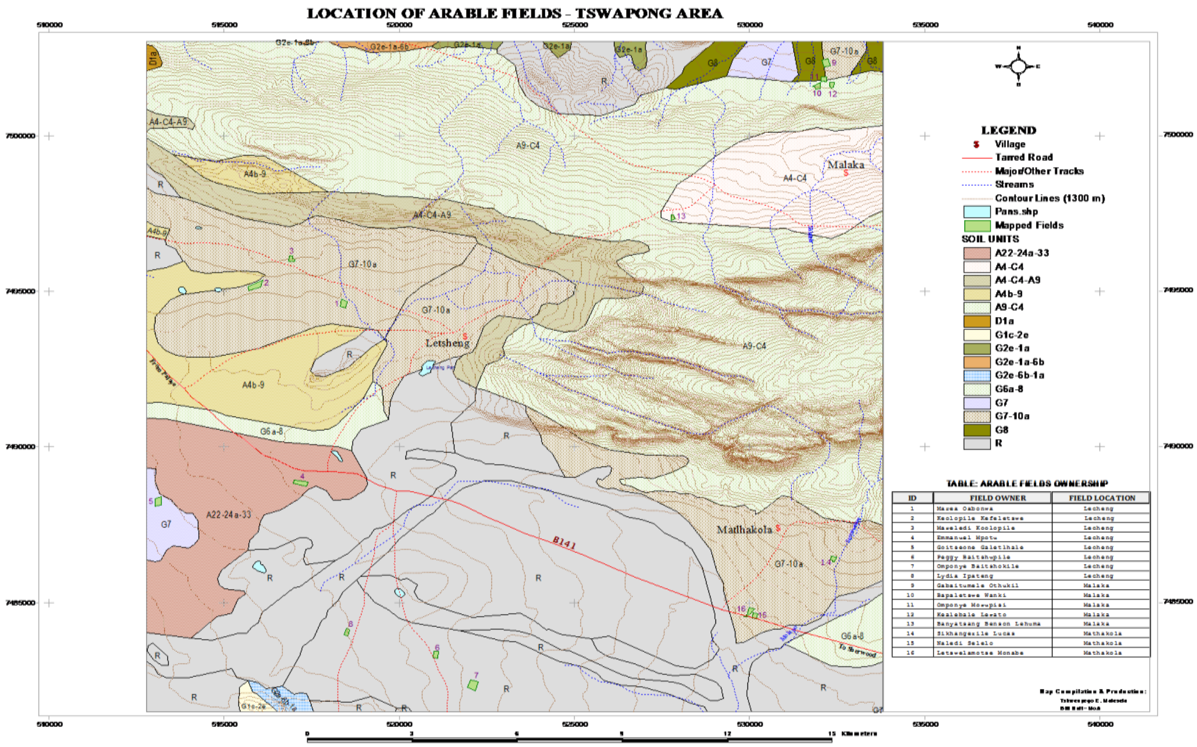


Figure 3.1: Soils at experimental site and surrounding areas. Source: Ministry of Agricultural Development and Food Security: Geographical Information System.

Table 3.1 Soil classification at Experiment I site.

NO	Field Location	Symbol	Soil description	FAO Classification
14	**(Matlhakola)**	• G7-10a	• Dark grayish brown massive coarse sandy loam to sandy clay loam. • Dark brown sandy clay loam to clay.	Orthic luvisols

Source: Ministry of Agricultural Development and Food Security, Botswana Government.

3.1.1.1 Soil sampling and analysis

Prior to construction of the sunken seedbeds and planting, soil samples were collected at 30 cm depth (the required plough depth in sandy soils) in the 0.32 ha plot. Soil samples were collected systematically in a grid form (Tan, 2005). A composite sample of approximately 500g was then taken to the Soil Science Laboratory at Botswana University of Agriculture and Natural Resources, where it was further prepared and analyzed for pH, EC, CEC, exchangeable bases, organic carbon, available phosphorus and total nitrogen. Each analysis was done following established standard protocols and procedures. Results of soil analysis before planting classified the soil as sandy (Table 3.2). Textural class, key fertility and nutrient status are presented in Table 3.2. The soils have very low cation exchange capacity (CEC), organic carbon and acidic pH of 5.85. Analysis of the compost shows that it had higher fertility status than the experimental soil (Table 3.2).

Table 3.2: **Initial Soil and Compost physical and chemical properties before planting.**

Parameters	Soil	Compost
pH	5.99	7.29
EC (mS/cm)	0.077	1.920
CEC (cmol (+)/kg	3.78	12.10
Total Carbon (%)	1.009	1.120
Total Nitrogen (%)	0.009	0.020
Available P (g/kg)	0.014	0.072
Ca (cmol (+)/kg	1.391	21.275
Mg (cmol (+)/kg	0.614	0.472
K (cmol (+)/kg	0.515	4.321
Na (cmol (+)/kg	0.1190	5.1991
Bulk density (g/cm^3)	1.43	-
Soil textural class	sand	-

3.1.1.2 Experimental Design and Treatments

On the 0.32 ha plot, sunken seedbeds were constructed each measuring 1mx1m and 0.3m deep. Sunken beds were constructed as a way of promoting conservation tillage and generally designed to reduce soil erosion and also improves water infiltration, water storage and thus yield potential and improve WUE. The spacing between each sunken bed was 1m* 1m. A completely randomized block design was used to arrange the growth patterns for the different treatments. The following treatments were used: **(1)**Soil + Urea (SU), **(2)** Soil + Urea + Compost (SUC), **(3**) Soil + Compost (SC), **(4**) Soil (Control). Soil and compost at appropriate ratios of 2:3 by volume were uniformly distributed among the relevant treatments and mixed thoroughly. For control treatments, plots were also excavated and the same soil was replaced without amendments. Each treatment, including the control, was replicated eight times resulting in a total of 32 sunken beds.

3.1.1.3 Planting and cultural practices

Seed of maize (Zea mays L.) variety Kalahari Early Pearl (KEP) from Seed Multiplication Unit (SMU) in the Department of Agricultural Research (DAR) were planted in the sunken seedbed. Plant spacing for each seedbed was 25cm by 25cm inter- and intra-row spacing and 5cm deep at the rate of 3 seeds/hill. Two (2) weeks after emergence (WAE) the seedlings were thinned to one per hill giving a plant population of 12 plants/sunken bed. At this stage, 50g of urea/ha/sunken bed was applied to the relevant treatments to balance N to the equivalence of 46kg N/ ha Urea. The quantity of urea application rate was calculated based on soil total N results (Table 3.2). Weeding was manual by hand hoeing and this started two (2) WAE to maintain the plots free of weed until sampling was carried out. It was necessary to maintain plots free of weed at all times because infestations differed depending on whether compost was used. The experiment was maintained as rain-fed from planting to sampling.

3.1.1.4 Data collection

3.1.1.4.1 Precipitation

Rainfall was measured with a rain gauge placed in the middle of the field at the experimental site and the accumulated monthly rainfall for the whole growing season was calculated.

3.1.1.4.2 Soil analysis

Soil samples were obtained before planting and after plant harvest. Soil pH was measured in 0.01 N calcium chloride solution using 1:2 soil to calcium chloride ratio. Soil EC was measured using portable EC meter in 1:2.5 soil to distilled water ratio as described by Reeuwijk. (2002). The CEC was determined by measuring ammonium concentration after the soil was extracted with ammonium acetate and then distilled and titrated with 0.01 hydrochloric acid as described by Reeuwijk. (2002). Organic carbon was analyzed by modified spectrophotometric Walkley and Black method as described by Souza *et al*. (2016). Available phosphorus in soil was extracted according to Bray and Kurtz method as described by Reeuwijk. (2002). Nitrogen percentage was determined by the micro–kjeldahl procedure which involve digestion in sulphuric acid–selenium mixture and hydrogen peroxide. The digest was distilled and ammonium was trapped into boric acid and the titrated with hydrochloric acid as described by Reeuwijk. (2002). Percentage soil nitrogen was then calculated using the formula by Estefan *et al*. (2013) below:

$$N\% = [D * 1.4007 * (Va - Vb) * N]\, Ws$$

Where:

Vs (ml) = volume of the acid used in the titration of the sample

Vo (ml) = volume of the acid used for blank titration

N = molarity 0.01 for HCL

1.4007 (mg) = constant related to the molecular weight of the N

Ws (g) = Weight of the soil sample

3.1.1.4.3 Plant Sampling and analysis

Ten plants per plot were sampled in the middle row and transported to BUAN Plant Analysis Laboratory where they were dried at 72 ^{o}C until they reached content dry weight after 48 hours. The dried samples were weighed and ground into a fine powder and placed into air tight bottles according to the treatments and replications. The weight biomass was expressed as above ground biomass. The nutrient concentration of N, P, K, Ca, Na and Mg were determined by the micro-Kjeldahl procedure which involve the digestion in a concentrated H_2SO_4 and H_2O_2. The plant digest were analyzed using Atomic Absorption Spectrophotometer (AAS) to find the concentration of Na, K, Ca, and Mg. Available P in plants was analyzed by modified spectrophotometric Walkley and Black method as described by Souza *et al*. (2016). The determination of total N in plants, the digest were distilled and titrated with 0.01 HCL and then total % N was calculated using the formula by Estefan *et al. (*2013) below:

$$N\% = [D * 1.4007 * (Va - Vb) * N] Ws$$

Where:

D = dilution factor

1.4007 (mg) = constant related to the molecular weight of N

Va (ml) = volume of the acid used in the titration of the sample

Vb (ml) = volume of the acid used for blank titration

N = molarity 0.01 for HCL

Ws (g) = Weight of sample

3.1.1.5 Statistical analysis

Data collected was subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) version 9.2.Where a significant F-test was observed, treatment means were separated using the Least Significant Difference (LSD) at risk level of $P < 0.05$.

3.1.2 Experiment II

A pot experiment was conducted at BUAN campus in a greenhouse located at Sebele Content Farm, 12 Kilometers north of the Gaborone City. The site is situated at latitude (24◦35´20´´S) and longitude (25◦56´20´´E). Its estimated terrain elevation above sea level is 993 meters, in the South Eastern part of Botswana, which is a semi-arid climatic zone.

3.1.2.1 Soil sampling and analysis

Pre- planting physico-chemical properties of the trial soil and compost are shown in Table 3.4. Before setting up the experiment, a soil sample of approximately 500 grams was collected from the field experimental plot for analysis of the following parameters; pH, EC, CEC, total N, available P, soil total carbon, and the exchangeable bases (K, Mg, Na and Ca). Each analysis was prepared according to established standard protocols and procedures. After setting up the green house experimental trial, samples were also collected from all the relevant treatments for analysis of total N and available P to be used in plants for the determination of NUE and PUE.

Table 3.4: Initial Soil and Compost physical and chemical properties used in greenhouse experiment before planting.

Parameters	Soil	Compost
pH	5.85	7.30
EC (mS/cm)	0.04	4.76
CEC (cmol (+)/kg	3.32	23.7
Total Carbon (%)	0.22	1.22
Total Nitrogen (%)	0.002	0.02
Available P (g/kg)	0.01	1.36
Ca (cmol (+)/kg	1.548	32.190
Mg (cmol (+)/kg	0.601	5.847
K (cmol (+)/kg	0.076	24.024
Na (cmol (+)/kg	Non-detectable	5.716
Bulk density (g/cm^3)	1.35	-
Soil textural class	sandy	-

3.1.2.2 Experimental design and treatments

The experimental design was 2*4 factorial arranged as a Randomized Complete Block Design (RCBD). The treatments were; (1) Soil + Urea (SU) (2) Soil + Urea fertilizer +Compost (SUC), (3) Soil + Compost (SC), (4) Soil (Control). Ammonium (NH_4^+) and nitrate (NO_3^-) are the inorganic forms of plant available nitrogen in soils. Based on soil analysis results as presented in Table 3.4 above 8.5g of urea was applied to the relevant treatments to balance N to the equivalence of 46kg N/ ha Urea. The two factors were level of irrigation and soil amendment treatment. The treatments comprised of two levels of irrigation, (W1= stressed at flowering stage, W2= irrigated). The crops received full irrigation until flowering stage, then irrigation was withheld from the other half of the maize crop whereby plants were subjected to progressive drought stress for approximately two weeks because maize water requirements tends to increase at periods of flowering and yield formation. Again during flowering period the uptake of nitrogen, phosphorus and potassium reaches a peak du Plessis. (2003). Water stress was imposed by withholding watering and allowing the soil moisture to be depleted naturally until the plants showed visible signs of wilting early in the morning. Once stress was established, plants were returned to the normal watering routine immediately. Well-watered plants were irrigated to field capacity throughout the experiment.

Thirty- two (32) cylindrical plastic pots of approximately (50L) 35 cm in diameter and 60 cm high with perforated bases were used. Sixteen pots (16) were filled with 72 kg of soil and the other sixteen pots (16) were filled with soil and compost at appropriate ratios of 2:3 in relevant treatments in the greenhouse set at 30^{o}c then separated into two sets.

3.1.2.3 Planting and cultural practices

Locally released maize (Zea mays L.) variety of Kalahari Early Pearl was obtained from Seed Multiplication Unit at the Department of Agricultural Research, Sebele. A total of five (5) seeds were sown per pot at a depth of 5cm and one week after emergence (WAE) seedlings were thinned to two per pot. Watering was done on alternate days using tap water. At the beginning of booting stage, there was an outbreak of sugarcane aphids (*Melanaphis sacchari*). Dectome insecticide was used to control aphids.

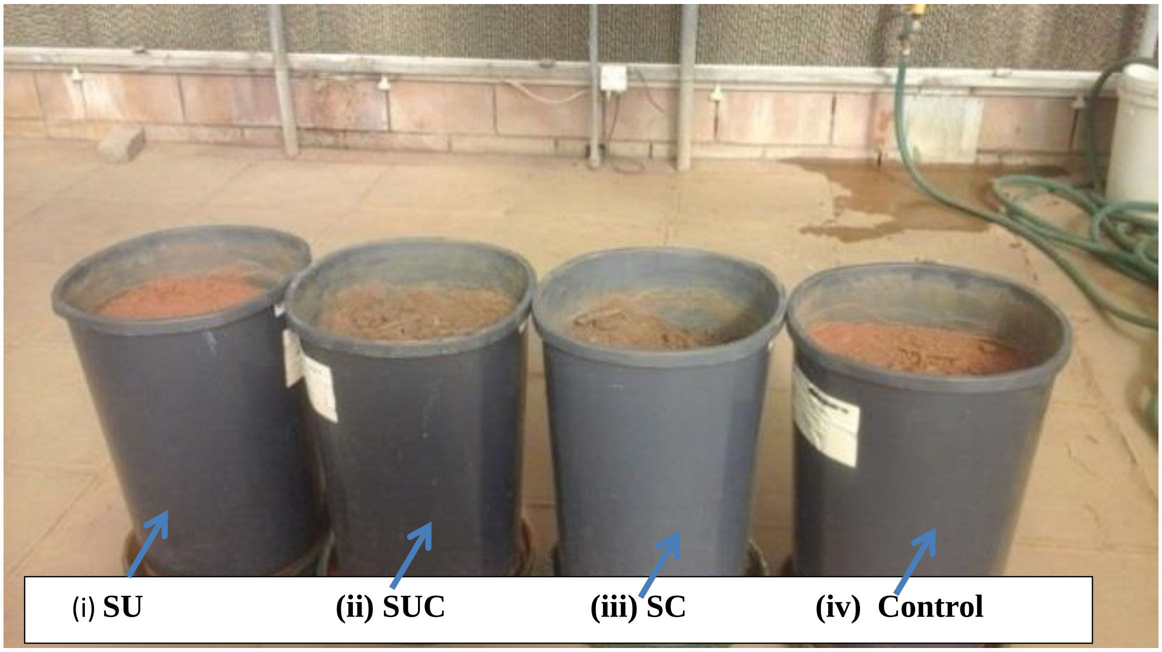


Figure 3.3 Greenhouse soil treatments layout.

3.1.2.4 Data collection

3.1.2.4.1. Soil and moisture content analysis

Soil pH, electrical conductivity, cation exchangeable capacity, organic carbon, soil available P, soil total nitrogen, and exchangeable bases (Na, Ca, K and Mg), were determined following the procedures described in experiment I section; 3.1.1.4.2. Soil moisture content was also monitored using MPKIT soil moisture sensor (ICT international, Armidale NSW Australia).

3.1.2.4.2 Plant growth parameters

The following components were measured from the randomly selected plants.

a). Days to 50% emergence: Assessment of plant emergence percentage was done at 10 days after planting by counting the number of seedling that has emerged. The outcome was expressed as percentage of the total expected from each treatment.

b). Number of leaves: Only healthy and fully matured or opened leaves were counted from the selected plants at flowering stage.

c). Plant height determination (*cm*): Plant height at vegetative stage and at early flowering stage were obtained. Measurements were done by using a tape measure from the soil surface to the top of end of the flag at the beginning of booting.

d). Stem diameter: The thickness of the stem was measured using a caliper to the nearest 1mm. The measurements were taken from the lower part of the main stem.

e). Days to 50% tasseling*:* Number of days from sowing to the date on which 50% plants produced tassels was recorded.

f). Days to 50% Silking: Days to silking was also be counted from the date of sowing to the date on which 50% plants produced silk.

g). Days to 90% physiological maturity*:* Appearance of black layer in seeds was used as criteria for physiological maturity, and was calculated as difference between date of physiological maturity and date of emergence.

h). Leaf area: To determine leaf area, the length and the greatest width of selected leaves was measured with a ruler.

3.1.2.4.3 Yield and yield components

a). Weight of cob (*g*): This was computed as the average weight from the randomly sampled plants using an electronic balance.

b). Grains per cob (*g*): The number of grains per each cob were recorded.

c). 100 seed weight (*g*): The 100 seeds were counted using the electronic seed counter and then weighed to the nearest 1mg.

d). Biomass yield: At harvest, roots were separated from the shoots and gently removed from the soil mass. Both the roots and shoots samples were obtained from all the pots. Samples were then oven dried at 72^{o}C for 48 hrs. Weights of the dry roots and dry shoots were measured using a sensitive balance at resolution ± 0.00g. Biomass yield was calculated as follows:

$$Biomass\ yield = (DW/FW) * 100$$

3.1.2.4.4. Leaf gas exchange and chlorophyll content measurements

a). Gas exchange

Photosynthetic rate (*A*), Stomatal conductance (*gs*), Transpiration rate (*E*) and internal CO_2 concentration (*Ci*) were measured using a portable photosynthesis system (LI- 6400/LI6400XT model). Readings were taken on the 2 fresh photo flag leaves.

b). Chlorophyll content

On daily basis the Minolta SPAD-502 plus, Konica Minoita meter was used to monitor chlorophyll concentration estimates on the fourth or fifth leaf down from the top of the plant. An average of three readings in leaf of each plant was used. The technique instantly measures the chlorophyll content of leaves by simply clamping the meter over the leaf and obtaining a chlorophyll content reading.

3.1.2.4.5 Determination of Water Use Efficiency

Photosynthetic water use efficiency was calculated by dividing leaf photosynthesis by leaf transpiration (Wilson *et al*., 2012).

$$PWUE = Pn/Tr\ (\mu molCO_2 . m^{-2.}S^{-1}/\ \mu mol\, H_2\, O.\ m^{-2.}\, S^{-1.})$$

PWUEL is the leaf level water use efficiency in, $\mu molCO_2/\mu molH_2O$

Where;

Pn is the photosynthesis rate in $\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$

Tr is the transpiration rate in $\mu molH_2O \cdot m^{-2} \cdot s^{-1}$.

3.1.2.4.6 Plant analysis after harvest

The nutrient concentration of N, P, K, Ca, Na and Mg were determined by the micro-Kjeldahl procedure which involve the digestion in a concentrated H_2SO_4 and H_2O_2. The plant digest were analyzed using Atomic Absorption Spectrophotometer (AAS) to find the concentration of Na, K, Ca, and Mg. Available P in plants was analyzed by modified spectrophotometric Walkley and Black method as described by Souza *et al*. (2016). The determination of total N in plants, the digest were distilled and titrated with 0.01 HCL and then total % N was calculated using the formula by Estefan *et al. (*2013) elaborated in experiment I section: 3.1.1.4.3.

3.1.2.4.7 Determination of Nitrogen Use Efficiency (NUE)

It was calculated from biomass yield at sampling. The Micro Kjeldahl method (AOAC, 2011) was used for the determination of nitrogen (N) concentration and the calculation of nitrogen use efficiency (NUE) was done following the formula by Moll *et al*. (1982) below.

$$NUE(kg/kg) = \frac{Nt}{N\ soil}\ X\ \frac{Bw}{Nt}$$

Where:

N soil = N supply from the soil plus the added N

Nt = total plant N at maturity

Bw = Aboveground Biomass weight at sampling

3.1.2.4.8 Determination of phosphorus use efficiency (PUE)

It was calculated from the biomass yield at maturity using the formula by (Baligar *et al*., 2001).

$$PUE\ (kg/kg) = {Bw(Total\ P\ in\ the\ plant\ (kg\ /\ plant)} \Big/ {Available\ P}$$

Where:

Available P = P available in the soil in kg / plant.

Bw = Aboveground Biomass weight at sampling

3.1.2.4.9 Statistical Analysis

Data collected was subjected to analysis of variance **(AVONA)** using the Statistical Analysis System (SAS) version 9.2.Where a significant F-test with observed, treatment means were separated using the Least Significant Difference (LSD) at risk level of $P<0.05$. The $P\leq0.05$ was used to derive the significant difference unless stated otherwise.

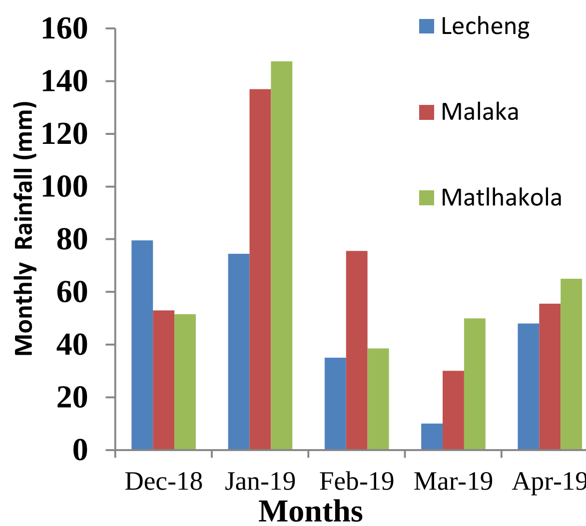
CHAPTER FOUR

RESULTS

4.1 Weather conditions at Lecheng extension areas

The extension area is composed of three villages, namely: Lecheng, Malaka and Matlhakola. The area received rainfall distribution as shown in (Figure 4.1) for the 2018/2019 growing season. Rains started very late around December 2018 and it is during this month when planting was implemented. Low rainfall was experienced in March 2019 when plants were at flowering stage. Generally, 2018/2019 growing season was a very dry year which resulted in poor plant stand and crop yields.

1a



2b

Figure 4.1: Rain gauge at Matlhakola (Figure 1a) and monthly rainfall recorded at Lecheng Agricultural Extension Area in 2018/2019 Figure 2b.

4.2 Preliminary response of maize and stover accumulation as influenced by compost amendments under rain-fed conditions at Lecheng Extension area during 2018/19.

In this rain-fed study it was observed that low rainfall experienced had strong effect on plant growth and biomass accumulation. However, treatments with compost amendments (SC and SUC) improved plant growth and stover production (Figure 4.2).

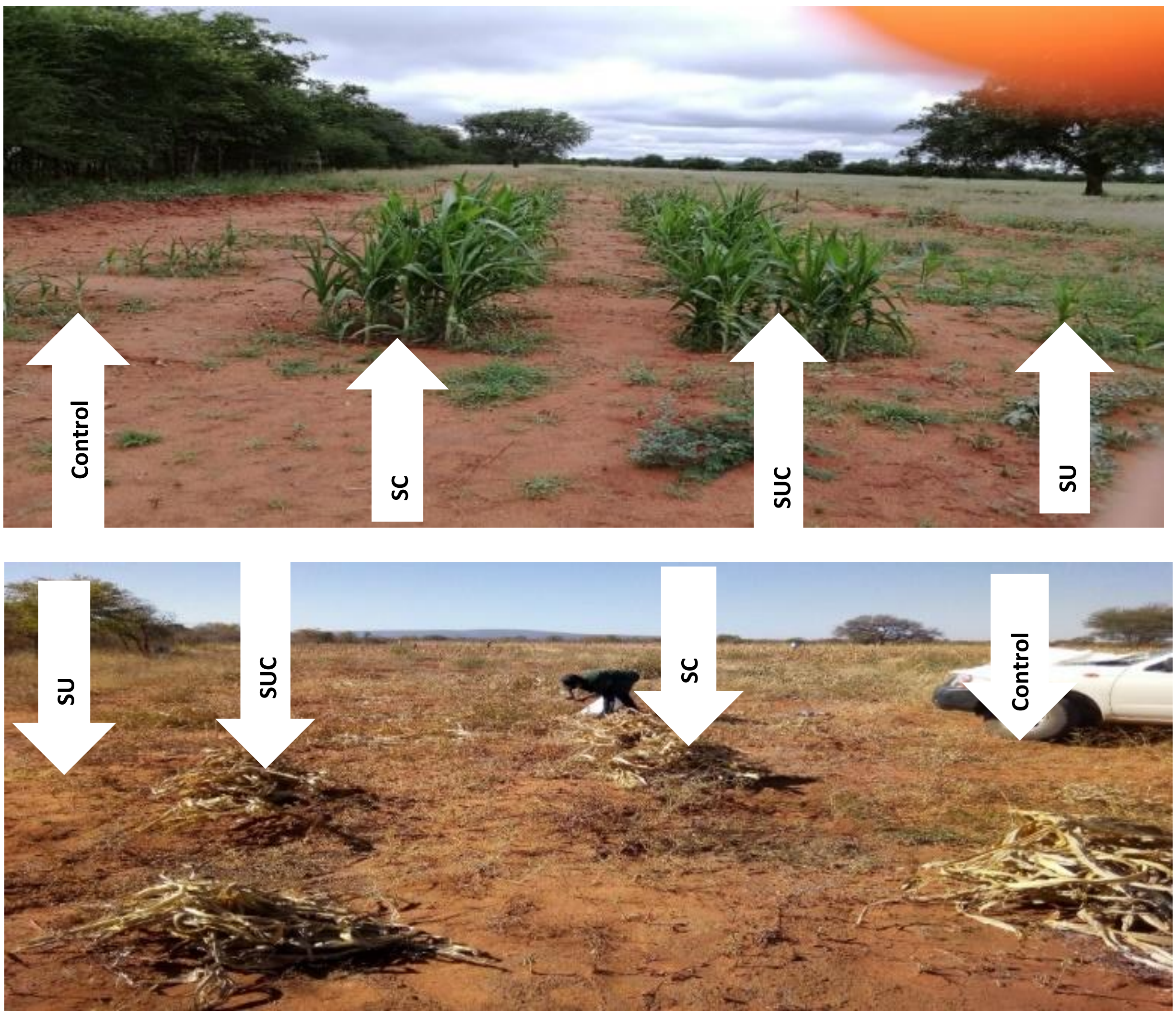


Figure 4.2: Plant growth and stover accumulated as influenced by compost treatment. Control (Soil), SU (Soil+ Urea fertilizer), SC (Soil+ Compost), SUC (Soil + Compost +Urea fertilizer).

4.3 Effect of compost amendments on maize nutrient concentration after harvest

The results presented in Table 4.1 shows maize nutrient content at harvest as influenced by compost amendments, under rain-fed condition. From Table 4.1, it was observed that there was no significant variation among the treatments with regard to N, Ca and Na level of concentration in maize. However, significant treatment differences were observed in maize plants with regard to P, K and Mg nutrient contents. Soil amended with compost resulted in higher levels of P, K and Mg in maize than those in the control treatments. It is worth noting that compared to controls, SU, SC and SUC treated plants had high nitrogen content although this is not statistically significant. Compared to the controls maize grown on soil amended with compost (SC and SUC) and urea fertilizer (SU) had high total P content. With regard to K and Mg nutrient concentration, a similar observation was made among the treatments where the highest and lower values were recorded in SC and control treatments respectively.

Table 4.1 Nutrient concentration in rain-fed maize at harvesting stage.

parameters	N	P	K ← %/plant nutrient content →	Ca	Mg	Na
Control	0.1872^{a}	0.00054^{b}	2.68717^{b}	0.19853^{a}	0.15389^{b}	0.00947^{a}
SU	0.2015^{a}	0.00375^{a}	2.16450^{b}	0.19489^{a}	0.17284^{b}	0.00894^{a}
SC	0.2057^{a}	0.00380^{a}	6.26570^{a}	0.25467^{a}	0.23069^{a}	0.00788^{a}
SUC	0.2202^{a}	0.00411^{a}	4.82460^{a}	0.21240^{a}	0.18305^{b}	0.00762^{a}
$LSD_{0.05}$	0.0665	0.0007	1.9277	0.0741	0.0442	0.0022

[a]Means followed by the same letters in the same column are not significant at $P<0.05$; The following acrynoms and words stand for: LSD - Least significant difference, Control - Soil, SU - Soil +Urea fertilizer, SC - Soil +Compost and SUC - Soil + Compost +Urea fertilizer.

4.4 Effect of compost amendments on soil chemical properties at 50% days to flowering stage and after harvest of maize crop.

Data in Table.4.2 shows the pH, EC, CEC, total carbon, exchangeable cations, total N, and available P concentration in soil at mid-growth stage and after harvest of maize as affected by compost amendments, under irrigation and water stressed conditions.

At flowering stage the pH values obtained with SU, SC and SUC were significantly higher than the control (Table 4.2). It is clear that application of compost amendments and urea fertilizer significantly increased soil pH values when compared to control. The results shows that SC treatment (6.54 and 6.56), SUC (6.50 and 6.52) and SU (6.26 and 6.25) had the highest effect in increasing pH values under irrigated as well as drought stressed experiments respectively. Control had the lowest pH values (5.77 and 5.85) under both irrigated and drought stress conditions respectively, which implies that addition of urea and amendment of soil with compost increased growth medium pH.

The results of EC revealed a significant change among treatments. The obtained results show that the application of compost under both conditions increased the EC values as compared to control treatments. Statistically the highest EC values were SC treatments (1.41dS/m and 1.78dS/m) and SUC treatments (1.39dS/m and 1.59dS/m), whereas the least values were recorded in SU treatments (0.11dS/m and 0.08dS/m) and control treatment (0.05dS/m and 0.07dS/m). Generally, control treatments had the lowest EC values under irrigated as well as water stressed conditions, which means amendment of soil with compost increased EC of the growth medium.

The results indicated that the values of CEC were significantly higher in soil amended with compost than the control and SU treatments. The highest CEC values were found in SC and SUC treatments (9.49 and 9.42cmol (+) /kg and 11.2 and 9.19cmol (+)/kg) respectively under both condition while the lowest CEC values were shown in SU (2.29 and 2.45cmol (+)/kg) and control treatments ranging between 2.19 and 2.42cmol (+)/kg under both conditions. Therefore amendment of soil with compost (SC and SUC) increased media CEC.

As shown in Table 4.2 compost amendments significantly increased total carbon compared to the control. The results revealed that the highest percent values were recorded in SUC (0.93 and 0.59) followed by SC treatments (0.50 and 0.50) under both conditions. The least total carbon values were obtained in SU (0.23 and 0.27) and control treatments (0.26 and 0.23) under irrigated as well as drought stress conditions.

The results also showed that total N and available P concentration in soil significantly responded to compost amendments and urea ($P<0.05$). The soils treated with compost and urea had more total N compared to soil without compost (control). Statistically there was no significant difference between the treatment means with respect to soil available P under both conditions. Compared to the control and SU treatments, application of compost amendments alone or in combination with urea increased the exchangeable Ca and K contents under irrigated as well as non- irrigated conditions. The highest Ca values were observed in SC treatment (1046.9 and 617.1cmol (+)/ kg) and SUC (907.8 and 374.1 cmol (+)/ kg). The least Ca value was obtained with SU (32.4cmol (+)/ kg) and control (37.1 cmol (+)/ kg) under drought stressed condition. Similar to exchangeable Ca, soil exchangeable K and Mg exhibited a significant increasing trend with compost amendment. The highest K values were obtained with SC (392.2 and 549.1cmol (+)/ kg) and SUC (318.8 and 582.8cmol (+)/ kg) in comparison with SU (30.8 and 29.9cmol (+)/ kg) and control (17.1 and 31.7cmol (+)/ kg) under both irrigated and water stressed conditions. As for Mg concentration, SUC treatment had the greatest values as compared to the rest of the treatments. The concentration of exchangeable Na was non-detectable under both conditions and similar results were revealed after harvest period.

Data was also collected at the end of the trial, which was at the time of harvest. Data shows that soil pH, EC, CEC, total carbon, total N, available P and exchangeable cations significantly responded to compost amendments with the exception of Na (Table 4.2). The highest pH values were obtained in SC, SU and SUC treatments. Generally the amendments of the acidic soil pH (5.85) with compost raised pH values. Similar trend was observed with EC results in both experiments. CEC as one of the major soil quality indexes was highly significant ($P<0.0001$). The highest CEC values were recorded in SC and SUC treatments; (12.4cmol (+)/kg and 9.42cmol (+)/kg), (10.9cmol (+)/kg and 11.2cmol (+)/kg) respectively. The lowest CEC values were shown in control (2.79 and 2.19cmol (+)/kg). As indicated total carbon was significantly greater in treatments incorporated with compost and urea fertilizer as compared to control treatments. With regard to total N and available P, the results revealed that there was significant increase with SU, SC and SUC treatments as compared to control treatments. Application of compost (SC) amendments alone or in combination with urea (SUC) showed marked increase in exchangeable Ca under irrigated as well as non- irrigated conditions over control and SU treatments (Table 4.2). The highest Mg concentration was noted with SUC treatments (308.2 and 599.1cmol (+)/kg) as compared to the rest of the treatments. Statistically, for K soil content the highest values were reflected in SC (279.8 and 250.7cmol (+)/kg) followed by SUC (193.4 and 159.6cmol (+)/kg) treatments while the least values were recorded in SU (27.9 and 29.2cmol (+)/kg).and control (29.8 and 27.2cmol (+)/kg) under both conditions.

Table 4.2: Profile of the medium on soil chemical properties at flowering and after harvest in the green house.

Treatments	Control		SU		SC		SUC	
Parameters	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**
<u>Flowering stage</u>								
pH (cacl$_2$)	5.77^b	5.85^b	6.26^{ab}	6.25^a	6.54^a	6.56^a	6.50^a	6.52^a
EC (dS/m)	0.05^b	0.07^c	0.11^b	0.08^c	1.41^a	1.78^a	1.39^a	1.59^b
CEC(cmol(+)/kg	2.42^b	2.19^b	2.29^b	2.45^b	9.49^a	9.42^a	9.19^a	11.2^a
Total carbon (%)	0.26^b	0.23^c	0.23^c	0.27^b	0.50^{ab}	0.50^b	0.93^a	0.59^a
Total N (%)	0.001^b	0.001^b	0.004^a	0.003^a	0.003^a	0.003^a	0.003^a	0.004^a
Available P(g/kg)	0.02^a	0.02^a	0.03^a	0.02^a	0.03^a	0.03^a	0.03^a	0.03^a
Ca(cmol(+)/kg	72.1^b	37.1^c	63.5^b	32.4^c	1046.9^a	617.1^a	907.8^a	374.1^{ab}
Mg(cmol(+)/kg	15.8^c	12.4^b	10.1^c	6.5^b	191.0^b	39.3^b	334.9^a	352.9 ^{a}
K(cmol(+)/kg	17.1^b	31.7^b	30.8^b	29.9^b	392.2^a	549.1^a	318.8^a	582.8^a
Na(cmol/kg)	ND	ND	ND	ND	ND	ND	ND	ND
<u>End of trial</u>								
pH (cacl$_2$)	6.45^b	5.95^c	7.36^a	6.45^b	7.25^a	7.23^a	6.69^b	7.04^a
EC (dS/m)	0.07^b	0.06^c	0.08^b	0.11^b	1.79^a	1.39^a	1.61^a	1.75^b
CEC(cmol(+)/kg	2.79^b	2.19^b	3.27^b	2.46^b	12.40^a	9.42^a	10.9^a	11.2^a
Total carbon (%)	0.27^b	0.16^c	0.45^a	0.67^a	0.49^a	0.50^a	0.52^a	0.44^b
Total N (%)	0.002^b	0.002^b	0.010^a	0.003^a	0.002^a	0.002^a	0.002^a	0.002^a
Available P(g/kg)	0.02^b	0.02^c	0.04^a	0.04^a	0.01^a	0.01^a	0.04^a	0.03^b
Ca(cmol(+)/kg	69.9^b	29.8^b	59.8^b	23.6^b	460.3^a	295.3^a	438.4^a	204.3^{ab}
Mg(cmol(+)/kg	16.9^b	11.2^c	46.4^b	47.8^b	129.2^b	276.9^b	308.2^a	599.1^a
K(cmol(+)/kg	29.8^c	27.2^c	27.9^c	29.2^c	279.8^a	250.7^a	159.6^b	193.4^b
Na(cmol/kg)	ND	ND	ND	ND	ND	ND	ND	ND

[a]Means followed by the same letters in the same column are not significant at P< 0.05. I and D represent irrigated and drought stressed conditions respectively, ND represent not detectable. Control (Soil), SU (Soil + Urea fertilizer), SC (Soil + Compost), SUC (Soil + Compost + Urea fertilizer).

4.5 Effect of soil moisture content on maize leaf chlorophyll content at vegetative stage

Results of ANOVA showed significant differences among treatments with regard to moisture content and chlorophyll content in both conditions (P< 0.05) (Figure 4.3). Comparatively there was no variation within drought stressed and irrigated treatments with respect to chlorophyll content although statistically SUC had the highest chlorophyll with 50.33 followed by SC and SU treatments with 34.90 and 34.75 SPAD values respectively whereas the lowest chlorophyll content was obtained in control under irrigated and drought stressed treatments (Figure 4.3a). In this study it was observed that maize plants subjected to reduced soil moisture had lower chlorophyll content as compared to irrigated condition. As summarized in Figure 4.3b significant differences were observed for soil moisture content subjected to compost amendments in which the greatest amount was noted with SC and SUC treatments under both conditions while the least amount was obtained with SU and Control treatments. It is clear that adding compost to sandy soil has a significant effect in retaining the moisture under both conditions.

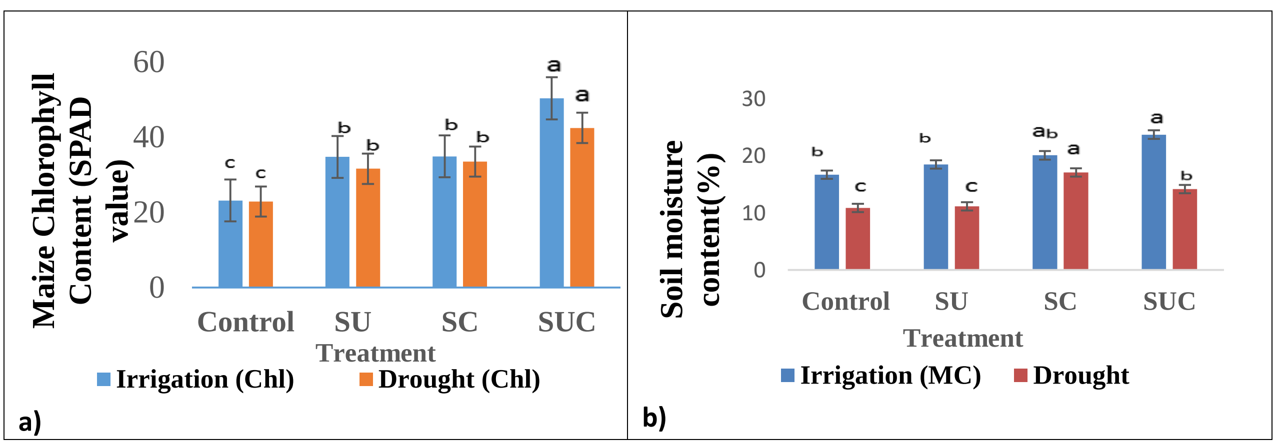


Figure 4.3: Effect of water stress and compost supplement on maize (a) leaf chlorophyll content and (b) soil moisture content at vegetative stage. Means followed by different letter are significantly different (P<0.05). Error bars indicate standard error of the means of plant chlorophyll (a) and soil moisture (b) contents, respectively. The following symbols mean: Control -Soil, SU - Soil +Urea fertilizer, SC- Soil +Compost and SUC - Soil+ Compost +Urea fertilizer).

4.6 Response of maize morphological characteristics as influenced by compost amendments and drought stress.

4.6.1 Plant height at reproductive stage

The results for plant height are presented in Table 4.3. ANOVA results shows that there was significant water and fertilizer amendment treatments and their interactions. Plant height variations of maize at reproductive stage indicated that plant height differed due to compost application under drought stress and irrigated conditions. The highest measurements for plant height were obtained from maize crops planted in SC and SUC while the shortest heights were noted from the control and SU treatments under both irrigated and drought stressed conditions. Under irrigated conditions SC and SUC treatment led to higher plants than control and SU treatments. Similar results were obtained under drought stress conditions whereby SC and SUC treated plants were taller. The results show that amendment of soil with compost improved plant growth under irrigated and drought stressed conditions.

4.6.2 Main stem diameter

The results for main stem diameter are presented in Table 4.3. ANOVA results shows there was significant water and fertilizer treatment. However, there was no significant interactions between water and fertilizer amendment for main stem diameter response. Under irrigated conditions SC and SUC treatment led to thicker plant stems than control and SU treatments. Similar results were obtained under drought stress conditions whereby SC and SUC treatments had thicker stems. The thickest stem diameter was observed in maize plants sown in SC (7.5) and SUC (8.4cm) under irrigated conditions and in SC (6.7cm) and SUC (6.8cm) under drought stressed conditions. These results were significantly different from control and SU treatment under both conditions.

The results show that amendment of soil with compost improved plant growth under irrigated and drought stressed conditions.

4.6.3 Number of leaves

The effects of water and fertilizer amendments and their interactions were non-significant at $P<0.05$ on the number of leaves (Table 4.3). However, there is tendency for the number of leaves to increase in SC and SUC treatment under both irrigated and drought stress conditions.

4.6.4 Leaf area (cm^2)

Treatments variation on leaf area is described in Table 4.3, it showed the influence of irrigation deficit and compost application on maize leaf area. The effects of water and fertilizer amendments were significant while their interactions were not. The average leaf area of maize plants under irrigated and drought stress conditions was 442.9cm^2 and 310.2cm^2 respectively (Table 4.3). Under irrigated conditions, SC and SUC treatments increased leaf area and these were 478.8cm^2 and 562.5cm^2 respectively. Under drought stress conditions only SUC led to increased leaf area of 466.4cm^2 over the other treatments. Generally, the results show that amendment of soil with compost improved plant growth under irrigated and drought stressed conditions.

4.6.5 Days to 50% Flowering

ANOVA for days to tasseling shows that water and fertilizer amendment treatments and their interactions were highly significant (Table 4.3). While data seems to be inconsistent among other treatments, it is apparent that SUC delayed tasseling by about 2 days compared to other treatments (controls and SU treatments), while SC delayed this response by a similar magnitude under both irrigated and drought stressed treatment. The results of ANOVA for days to silking shows water and fertilizer amendments and their interactions were significant.

The treatments SC and SUC delayed days to silking under both irrigated and drought stressed treatments compared to controls. These were 60 and 59 days under SC and SUC respectively compared to 56 days of controls.

4.6.6 Days to 90% physiological maturity

ANOVA for days to physiological maturity shows that water and fertilizer amendment treatments and their interactions were highly significant (Table 4.3). Under irrigated conditions, SU, SC and SUC delayed maize to reach physiological maturity. Days to reach maturity were SU (119 days), SC (119 days) and SUC (120 days) compared to 118 days of controls. Under drought stress SU and SC delayed days to maturity with 121 days and 119 days respectively while SUC treatments reached maturity at the same time with Controls at 117 days each.

Table 4.3: Response of maize morphological characteristics as influenced by compost amendments and drought

Treatment	Plant height(cm)	Stem diameter (cm)	Number of leaves	Leaf area (cm^{2})	Days to 50% tasseling	Days to 50% silking	Days to 90% maturity
				Irrigated trial			
Control	93.0^{b}	4.3^{c}	9.8^{b}	269.9^{b}	57^{b}	56^{c}	118^{c}
SU	95.0^{b}	5.7^{b}	11.3^{a}	460.3^{ab}	57^{b}	56^{c}	119^{b}
SC	221.5^{a}	7.5^{a}	12.0^{a}	478.8^{a}	56^{c}	59^{b}	119^{b}
SUC	222.0^{a}	8.4^{a}	12.8^{a}	562.5^{a}	59^{a}	60^{a}	120^{a}
Mean	145.9	10.1	11.5	442.9	57	58	119
LSD$_{0.05}$	18.64	0.98	2.26	195.23	0	0	0
				Drought stressed			
Control	72.0^{b}	3.9^{b}	9.5^{bc}	214.4^{b}	56 ^{c}	58^{b}	117^{c}
SU	98.5^{b}	4.4^{b}	9.0^{c}	272.9^{b}	57^{b}	57^{c}	121^{a}
SC	166.5^{a}	6.7^{a}	11.3^{a}	287.0^{b}	55^{d}	57^{c}	119^{b}
SUC	152.8^{a}	6.8^{a}	10.8^{b}	466.4^{a}	59^{a}	59^{a}	117^{c}
Mean	109.9	5.5	10.2	310.2	57	58	118
LSD$_{0.05}$	44.8	1.09	1.71	169.31	0	0	0
				ANOVA			
Water	0.0001****	0.0001****	0.097^{ns}	0.001***	0.0001****	0.0001****	0.000^{1****}
Fertilizer	0.0001****	0.0001****	0.146^{ns}	0.001***	0.0001****	0.0001****	0.0001****
F * W	0.01*	0.280^{ns}	0.749^{ns}	0.503^{ns}	0.0001****	0.0001****	0.0001****

^{a}Means followed by the same letters in the same column are not significant at P<0.05,; *,**,***,**** denote significant difference at P<0.05, P<0.01, P<0.001and P<0.0001 and respectively; and ns= not significant. Control (Soil), SU (Soil+ Urea fertilizer), SC (Soil +Compost), SUC (Soil+ Compost +Urea fertilizer).

4.7 Impact of drought stress and compost amendments on maize yield contributing components

4.7.1 Cob dry weight (g)

ANOVA for cob dry weight shows that water and fertilizer amendment treatments and their interactions were highly significant (Table 4.4). Under irrigated conditions, the SC and SUC treatments increased cob dry weight. The weights were SC (230.3g) and SUC (140.5g). Under drought stress, the SU, SC and SUC increased cob weights by compared to controls. The weights were SU (91.8g), SC (86.7g) and SUC (127.6g), while that of the controls were 25.7g. The results show that amendment of the soil with compost (SC and SUC) increased maize cob weight under irrigated and drought stressed conditions.

4.7.2 Number of grains per cob

ANOVA for number of grains per cob shows that water and fertilizer amendment treatments and their interactions were significant (Table 4.4). Under irrigated conditions, SU SC and SUC increased number of grains/cob compared to controls. These were 43 (SU), 188 (SC) and 127 (SUC) grains per cob while controls did produce grain at the time of harvest. Under drought stress conditions, SU, SC and SUC treatments increased the number of grains/cob compared to the controls. These were 30 grains/cob (SU) grains/cob, 92 (SC) grains/cob, 82 grains/cob (SUC) while those for controls were 8 grains per cob. The results shows that compost amendment increased the number of grains per cob in maize under both irrigated and drought stress conditions.

4.7.3 100 seed weight (g)

ANOVA for 100 seed weight shows that there was no significant water effect, while fertilizer amendment treatment was significant (Table 4.4). The interaction between water and fertilizer amendments was however insignificant. Under irrigated conditions SU, SC and SUC increased the 100 seed weight over the control. There were 8.3g (SU), 55.3g (SC) and 68.3g (SUC) compared to controls where there was no grain. Under drought stress conditions, SC and SUC increased 100 seed weight compared to SU and controls where there were no grain production in these treatments. The results show that soil amendment with compost (SC and SUC) increased 100 seed weight in maize.

Table 4.4: Impact of drought stress and compost amendments on maize yield components.

Treatments	Cob weight(g)	Grains/ cob	100 seed weight(g)
		Irrigated trial	
Control	13.9^{c}	0^{c}	0^{b}
SU	67.2^{c}	43.3^{bc}	8.3^{b}
SC	230.3^{a}	188^{a}	55.3^{a}
SUC	140.5^{b}	127^{ab}	68.3^{a}
Mean	112.9	89.6	33.1
$LSD_{0.05}$	72.8	102.93	30.59
		Drought stressed	
Control	25.7^{b}	8.8^{c}	0.0^{b}
SU	91.8^{a}	30.0^{b}	0.0^{b}
SC	86.7^{ab}	92.3^{a}	41.5^{a}
SUC	127.6^{a}	82.3^{a}	50.3^{a}
Mean	83.1	53.4	23.1
$LSD_{0.05}$	63.52	92.44	38.39
		ANOVA	
Water	0.047^{*}	0.09^{ns}	0.209^{ns}
Fertilizer	0.0001^{****}	0.001^{***}	0.0001^{****}
F * W	0.001^{***}	0.337^{ns}	0.856^{ns}

[a]Means followed by the same letters in the same column are not significant at $P< 0.05$,; *,**, ***, **** denote significant differences at, and $P< 0.05$, $P < 0.01$,$P< 0.001$ and $P< 0.0001$ respectively; and ns- not significant difference at $P<0.05$. LSD: Least significant difference. Control (Soil), SU (Soil +Urea fertilizer), SC (Soil +Compost), SUC (Soil +Compost +Urea fertilizer).

4.8: Accumulation of maize biomass at vegetative and physiological maturity stages as influenced by compost amendments and drought stress.

4.8.1 Biomass at vegetative stage

There was no significant interactions between drought and fertilizer amendments (Table 4.5). Fertilizer amendment treatments resulted in significant difference at $P<0.001$. Within the treatments under irrigated condition, the difference were significant with maximum dry matter of 18.08g yielded from maize plants sown in combination of SUC as compared to other treatments. Under drought stress treatment SC and SUC treatments had significantly higher vegetative biomass of 12.94 and 10.84g/plant respectively (Table 4.5). The results shows compost amendments (SC and SUC) compared to Control and SU increased biomass production in maize under both irrigated and drought stressed conditions.

4.8.2 Shoot biomass at maturity

There was no significant interaction between drought and fertilizer amendment treatments (Table 4.5), while fertilizer amendment treatments indicated significant difference at $P<0.0001$. Under irrigated conditions, SC and SUC produced significantly higher biomass of 116.80 and 179.33g/plant respectively. Similar results were obtained under drought stress where SC produced 139.99g/plant and SUC resulted in 177.80 g/plant. In general, the highest figures of shoot biomass weight were recorded with combination of SUC under irrigated and water stress conditions while the lowest figures were noted in SU and Control treatments under both conditions (Table 4.5).

4.8.3 Root biomass at maturity

Concerning the effect of drought and the interaction of water * fertilizer amendment data presented in Table 4.5 shows that there was no significant difference on root biomass at maturity stage though fertilizer addition induced significant difference at $P<0.001$.

Total root biomass varied among all the treatments except in SC and SUC treatment increased root biomass under irrigated and drought stressed conditions. It is indicated from this Table 4.5 that SC and combination SUC under both conditions yielded highest root dry weights (121.76 and 50.41g/plant) and (82.46 and 57.74g/plant) respectively, statistically greater than weights of root biomass in SU and control maize plants. Therefore, compost amendment (SC and SUC) treatments increased the root biomass compared to SU and the control.

4.8.4 Total biomass at physiological maturity

The results shows that drought and its interaction with fertilizer amendments were not significant on biomass production (Table 4.5). Fertilizer amendment treatments were highly significantly different at $P<0.0001$ (Table 4.5). Under irrigated conditions, SC and SUC produced 238.64 and 261.73g/plant respectively, while SU and Control produced 33.8 and 57.69g/plant respectively. Under drought stress, SC and SUC produced 190.40g/plant and 235.54g/plant respectively, while SU and Control treatment produced 23.50 and 65.35g/plant respectively. Therefore, incorporation of compost in the soil (SC and SUC) resulted in higher biomass under both irrigated and drought stress conditions compared to SU and control treatments.

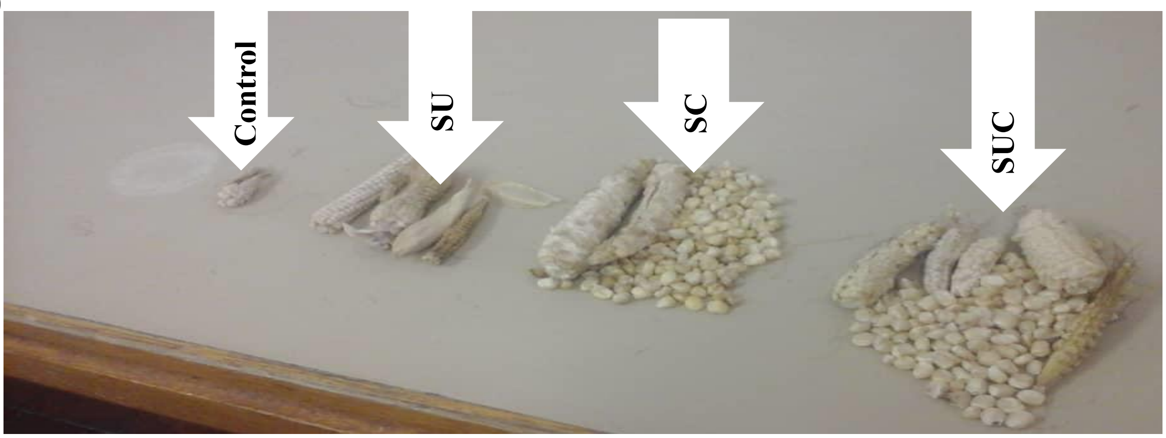
Table 4.5: Biomass production of maize as influenced by compost application and drought

Treatment	Biomass at vegetative stage (g)	Shoot biomass (g)	Root biomass (g)	Biomass at maturity (g)
		Irrigated trial		
Control	2.91[c]	26.70[c]	7.10[c]	33.80[b]
SU	6.68[bc]	43.53[c]	14.16[bc]	57.69[b]
SC	16.48[ab]	116.8[b]	121.76[a]	238.64[a]
SUC	18.08[a]	179.33[a]	82.46[ab]	261.73[a]
Mean	11	91.59	56.4	238.5
LSD0.05	11.22	53.69	71.02	73.41
		Drought Stressed		
Control	4.63[b]	15.51[b]	7.79[b]	23.50[b]
SU	4.24[b]	46.25[b]	19.10[b]	65.35[b]
SC	12.94[a]	139.99[a]	50.41[a]	190.40[a]
SUC	10.84[ab]	177.80[a]	57.74[a]	235.54[a]
Mean	8.9	94.9	33.8	127.5
$LSD_{0.05}$	7.19	60.92	28.95	74.2
		ANOVA		
Water	0.223 [ns]	0.821[ns]	0.09[ns]	0.431 [ns]
Fertilizer	0.001[***]	0.0001[****]	0.001[***]	0.0001[****]
F * W	0.590ns	0.857[ns]	0.170[ns]	0.871[ns]

[a]Means followed by the same letters in the same column are not significant at P< 0.05,; *,**, ***, **** denote significant differences at P< 0.05, P < 0.01, P< 0.001 and P< 0.0001 respectively; and ns- no significant difference at P<0.05. LSD is least significant difference. Control -Soil without amendments, SU - Soil +Urea fertilizer, SC - Soil +Compost, SUC -Soil +Compost +Urea fertilizer.

(a)

(b)



(c)

Figure 4.4: An overview of maize performance as influenced by water regime and soil compost amendments: **(a)** Maize growth under irrigated and drought stressed conditions, **(b)** Root biomass (**c**) grain yield of maize under soil amended using compost and urea fertilizer.

4.9 Nutrient concentration in maize at harvesting stage – Green house experiment

Data in Table 4.6 shows maize nutrient content at harvest as influenced by compost amendments under irrigated and drought stressed conditions. There was no significant interactions between drought stress * fertilizer amendments on N concentration. On the other hand, the effect of fertilizer amendments and drought stress on N content reflects significant different at $P<0.0001$. The greatest N concentration was recorded in SU treatment under both irrigated and drought stressed conditions.

Concerning phosphorus the results shows that there was no significant interaction between drought stress * fertilizer amendment on P content whereas fertilizer amendment had a significant effect ($P<0.0001$). Drought stress also had a significant effect on maize P content at $P<0.05$. Among the treatments control recorded the greatest P concentration as compared to the rest of the treatments under both irrigated and drought stressed conditions. The results on potassium (Table 4.6) demonstrated that water stress and fertilizer amendments and its interactions were all significant at $P< 0.0001$. The highest K content was obtained from compost amended soil (SC and SUC).

Table 4.6: **Nutrient concentration in maize at harvesting stage – Green house experiment**

parameters	N		P		K		Ca		Mg		Na	
	← % plant nutrient content →											
Treatments	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**
Control	0.0923[b]	0.1025[d]	0.00135[a]	0.0021[a]	1.0938[b]	0.9611[b]	0.1427[c]	0.1416[c]	0.1104[b]	0.1479[a]	0.0343[ab]	0.0226[b]
SU	0.1809[a]	0.1938[a]	0.00020[c]	0.0002[b]	0.8491[b]	0.8854[b]	0.2494[bc]	0.2187[bc]	0.1885[a]	0.1506[a]	0.0408[a]	0.0221[b]
SC	0.0971[b]	0.1250[c]	0.00043 b	0.0005[b]	2.0155[ab]	6.4081[a]	0.5181[a]	0.3423[a]	0.1863[a]	0.1567[a]	0.0305[ab]	0.0215[b]
SUC	0.0980[b]	0.1545[b]	0.00024[c]	0.0008[b]	2.9192[a]	6.8012[a]	0.4269[ab]	0.2823[ab]	0.1689[a]	0.1258[a]	0.0266[b]	0.0321[a]
LSD(0.05)	0.05	0.02	0.21	0.0007	0.05	0.69	1.247	0.11	0.01	0.05	0.0002	0.0064
ANOVA												
Fertilizer	0.0001****		0.0001****		0.0001****		0.0001****		0.028*		0.0441*	
Water	0.0001****		0.01*		0.0001****		0.0283*		0.095[ns]		0.001***	
F*W	0.3762[ns]		0.0860[ns]		0.0001****		0.301[ns]		0.043*		0.010*	

[a]Means followed by the same letters in the same column are not significant at P<0.05,; *,**,***,**** denote significant difference at P<0.05, P<0.01, P<0.001 and P<0.0001 respectively; and ns=not significant. I and D represent Irrigated and drought stress conditions respectively. LSD: Least significant difference. Control (Soil), SU (Soil + Urea fertilizer), SC (Soil+ Compost), SUC (Soil +Compost + Urea fertilizer).

4.10 a). Nitrogen and phosphorus use efficiency of maize at maturity stage.

4.10 b). Nitrogen use efficiency in maize

Drought stress and fertilizer amendment interactions were not significantly different ($p>0.05$) on nitrogen use efficiency (NUE) at maturity stage whereas fertilizer amendment treatments had significant effect ($P<0.0001$) on NUE in maize at physiological maturity (Table 4.7). The highest NUE was detected on maize plants grown in SUC (24.66g/kg and 14.17g/kg) as compared to other treatments under both conditions. The lowest NUE was noted in SU (2.25g/kg), SC (9.22g/kg) and control treatments (2.46g/kg) under irrigated conditions.

4.10 c). Phosphorus use efficiency of maize under different water regime and compost amended soil.

Data for phosphorus use efficiency (PUE) of maize is given in Table 4.7. PUE was also influenced by compost amendment and irrigation deficit conditions. The interactive effects of drought stress and fertilizer amendment were highly significant at $P<0.001$. The effects of drought stress and fertilizer amendment were also highly significant at $P< 0.0001$. The highest PUE was noted in SUC treatment (210.35kg/kg) and SC (141.89 kg/kg) under irrigated condition and the lowest was recorded in control and SU (34.11 kg/kg and 17.08 kg/kg) treatments respectively under irrigated condition (Table 4.7). A similar behavior was observed in maize plants under drought stressed condition. Therefore, amendment of soil with compost (SC and SUC) treatment increased PUE under both irrigated and drought stressed conditions.

Table 4.7: Nitrogen Use Efficiency and Phosphorus Use Efficiency of maize at maturity

	Nitrogen use efficiency (NUE) kg/kg		**Phosphorus use efficiency (PUE**	
TREATMENTS	***I***	***D***	***I***	***D***
Control	2.46 [b]	2.79[b]	17.08[b]	2.40[b]
SU	2.25[b]	4.31[b]	34.11[b]	6.65[b]
SC	9.22[b]	7.88[ab]	141.89[a]	20.37[a]
SUC	24.66[a]	14.17[a]	210.35[a]	24.71[a]
MEAN	8.74	7.29	100.86	13.53
LSD$_{(0.05)}$	10.68	6.69	81.9	10.42
		ANOVA		
Fertilizer	0.0001****		0.0001****	
Water	0.265[ns]		0.0001****	
Fertilizer* water	0.169[ns]		0.001***	

[a]Means followed by the same letters in the same column are not significant at P<0.05,; *,**,***,**** denote significant difference at P<0.05, P<0.01, P<0.001 and P<0.0001 respectively; and ns=not significant. I and D represent Irrigated and drought stress conditions respectively. LSD: Least significant difference.

4.11: Effect of compost amendments and drought stress on photosynthetic parameters of maize.

Fertilizer amendments application and its interaction with drought stress significantly ($P<0.0001$) affected the rate of photosynthesis in maize (Table 4.8) while water treatment had no significant effect on the rate of photosynthesis in maize. A non-significant difference was observed among the treatments with regard to photosynthetic rate of maize under irrigated condition. Under drought stressed condition control exhibited the lower photosynthetic rates compared to other treatments. Amendment of soil with compost (SC and SUC) led to increased photosynthesis in maize under drought stress, but not under irrigated conditions.

With regard to transpiration, the interactions of fertilizer amendment and drought stress had significant effect at $P<0.05$ on transpiration rates (Table 4.8). Under both conditions maize plants sown in Control and SU treatments exhibited significantly higher rates of transpiration than in SC and combination of SUC (Table 4.8). Transpiration rate was significantly ($P<0.0001$) affected by fertilizer amendment while drought stress also significantly ($P<0.001$) affected the rate of transpiration in maize plants. Amendment of soil with compost (SC and SUC) significantly reduced transpiration under both irrigated and drought stressed conditions.

The results also show that fertilizer amendment and drought stress had no significant differences in the internal CO_2 of maize plants although their interactions were significant ($P< 0.05$) on internal CO_2 concentration. Amendment of soil with compost (SC and SUC) led to reduction in internal CO2 concentration under drought stress condition, but not under irrigated conditions.

As Table 4.8 indicates, drought stress, fertilizer amendments and interaction of fertilizer amendment and drought stress had no significant effect on stomatal conductance. There was no significant differences in stomatal conductance among all the treatments under both conditions.

The results on WUE shows significant difference between drought stress treatments and interaction of water and fertilizer amendments at ($P < 0.05$). WUE was significantly ($P < 0.001$) affected by fertilizer amendments. As indicated in Table 4.8, there was no significant difference among irrigated treatments with regard to WUE. Maize plants under water deficit condition had similar trend of WUE compared to their corresponding irrigated treatments except that control exhibited the lowest value (1.99 g/g^{-} plant). Therefore, amendment of soil with compost (SC and SUC) led to increased WUE and these were not significantly different from soil amended with urea fertilizer (SU).

4.8: Photosynthesis, Transpiration, internal CO_2, Stomatal conductance and WUE of maize at flowering stage.

Treatments	Photosynthesis (A) µmol CO_2 m^{-2} s^{-1}		Transpiration (E) mmol H_2O m^{-2} s^{-1}		Internal CO_2 (Ci) µmol m^{-2} s^{-1}		Stomatal conductance (g) µmol m^{-2} s^{-1}		Water Use efficiency (WUE) (µmol CO_2/mmol H_2O)	
	I	**D**	**I**	**D**	**I**	**D**	**I**	**D**	**I**	**D**
Control	25.74[a]	14.84[b]	9.60[a]	7.43[a]	339.58[a]	361.49[a]	1.28[a]	1.10[a]	2.70[a]	1.99 [b]
SU	26.14[a]	29.13[a]	9.00[a]	7.29[a]	354.40[a]	328.99[bc]	1.27[a]	1.13[a]	3.01[a]	4.00[a]
SC	26.98[a]	27.25[a]	1.24[b]	1.35[b]	333.29[a]	339.40[b]	1.24[a]	1.35[a]	2.98[a]	3.68[a]
SUC	23.47[a]	28.96[a]	1.41[b]	1.25[b]	342.84[a]	327.38[c]	1.41[a]	1.25[a]	2.62[a]	3.63[a]
$LSD_{(0.05)}$	5.93	4.54	1.43	0.55	29.98	11.81	0.49	0.27	0.72	0.78
					ANOVA					
Fertilizer	0.0001[****]		0.0001[****]		0.125[ns]		0.321[ns]			0.001[***]
Water	0.632[ns]		0.001[***]		0.510[ns]		0.658[ns]			0.01[*]
F* W	0.0001[****]		0.02[*]		0.01[*]		0.654[ns]			0.01[*]

[a]Means followed by the same letters in the same column are not significant at P<0.05,; *,**,***,**** denote significant difference at P<0.05, P<0.01, P<0.001 and P<0.0001 respectively; and ns=not significant. I and D represent Irrigated and drought stress conditions respectively. LSD: Least significant difference.

CHAPTER FIVE

DISCUSSION

5.1 Characteristics of soils at the study site

Soils at the experimental study site was classified as orthic-luvisol and this soil types are coarse sandy loam. Sandy soils generally have low CEC hence less ability to hold and retain nutrients. These soils are moderately deep to very deep with low nutrient due to very severe leaching and low organic matter content (Simon and Czacko, 2014). The results from the initial soil analysis showed low soil fertility levels of the experimental site. This was indicated by the low levels of basic cations (Ca, K, Mg, and Na). Water stress and low soil nutrient content adversely affects plant growth which ultimately decreases the final yield. Hence soils amended with compost (SC and SUC) alleviate the negative effects of drought stress and low soil fertility on plants. This shows substantial effect of compost amendment on utmost parameters investigated during the study period.

5.2 Effect of compost amendment on soil chemical and physical properties.

The results of this experiments show a positive effect of compost application on soil pH, EC, CEC, total C, total N, available P and exchangeable cations (Ca, Mg and K). The significant increase of soil pH in the study work was predominantly due to the initial high pH values of the compost added. Addition of compost is essential to provide necessary nutrients for crops and improving soil physico-chemical properties (Meena *et al*., 2015). It has been observed that the addition of soil amendments (organic and inorganic) has great potential for increasing soil pH (3.2–7), reducing the solubility of trace metals by more than 80%, and stabilizing the soil (Pardo *et al*., 2017). The results are in line with the work of Liu *et al. (*2019) on remediation effectiveness of vermicompost for a potentially toxic metal contaminated tropical acidic soil, where vermicompost amendment increased soil pH by 0.7 to 1.5 units. Mostly the amendment of acidic soil with compost increase soil pH values to levels that are more suitable for most crops growth. A study by Brar *et al.* (2015) showed that integrated use of inorganic fertilizer along with organic fertilizer (100% NPK + FYM) improved soil pH which resulted in higher maize and wheat yields. These findings confirmed the effectiveness of compost in enhancing these properties Ch'ng *et al*. (2015) and Sanusi *et al*. (2018), in which the treatments with organic amendments significantly increased soil pH. According to Agegnehu *et al*. (2016) composts have a liming effect because of their richness in alkaline or base cations such as Ca, Mg, Na, and K which were liberated from organic matter through mineralization. The pH change is a key factor for regulating the solubility and availability of nutrients in the soil.

Electrical conductivity (EC) is a soil parameter that indirectly determines the total concentration of soluble salts and also a direct salinity measurement. The results in this experiment revealed that the overall EC was lower in SU and control soil treatments under both conditions as compared to compost treated soils (SC and SUC). The EC values of soil treated with compost ranged from 1.39 to 1.78 (ds/m) in both conditions compared with control. The increase in the soil EC values can be explained by the inputs of nutrients and salts contained in the compost. Integration of composts into soil increases the salt content as well as soil EC, especially if high rates of compost are applied (Angelova *et al*., 2013).

The results of the study indicated elevation of CEC with compost treated soils (SC and SUC) as compared to non- compost soils, this could also be attributed to the fact that compost have a higher cation exchange capacity and that can therefore increase CEC. Liu *et al*. (2012) also indicated that compost amendment results in an increase of CEC due to input from stabilized OM being rich in functional groups such as carboxylic and phenolic acid groups being released into the soil exchange sites. Agegnehu *et al.,* (2016b) suggested that enhanced CEC increased soil fertility by increasing nutrient availability through nutrient retention in soil instead of leaching through soil profile out of the rooting zone.

The results also exhibited a higher total carbon content in soils treated with compost (SC and SUC) than the control and urea treatments. The increase of soil total carbon with addition of compost amendments may be associated by high organic matter content of compost. The results concur with the findings of Bouajila and Sanaa (2011) who reported that the application of compost from manure and household waste resulted in a significant increase in organic carbon with the compost treatment being the most efficient. Their results showed that the application of household waste compost and manure improved the organic carbon. Trupiano *et al*. (2017) also found that application of compost and biochar, alone or in combination, increased soil TOC content than that in the unamended soils, which is indicative that biochar and/or compost applications to soils can enhance C accumulation and sequestration.

This study revealed that compost amendments showed a slight effect on soil available P, as compared to control treatments, which may be partially attributed to the fact that compost released phosphorus and organic acids from decomposition of organic matter. A study by Mensah and Frimpong (2018) found out that the application of compost significantly increased the soil available P. The structural improvements made to soil by increasing the quantity of SOM can improve plant P availability by allowing for greater root access to soil P stores (Schröder *et al*., 2011). Similarly, Mao *et al.* (2008) and Olowolafe (2008) also observed a higher phosphorus content of the soil where cattle manure or municipal waste was used for a period of 5 years on maize compared to inorganic fertilized soil.

The results for exchangeable cations, such as potassium (K), calcium (Ca) and magnesium (Mg), significantly increased with the compost amendment (SC and SUC) treatments. This implies that compost was very beneficial for plants as a source of exchangeable cations. The findings are in line with Adugna (2016) who expressed that the mineralization of compost would release many nutrients into the soil so that the nutrients would be greatly increased.

5.3 The effect of soil amendment under irrigated and drought stress conditions on morpho-physiological responses of maize.

5.3.1 Plant height

The application of compost in this study had a significantly positive effect on the growth and yield attributes of maize, when applied together with urea fertilizer. The data obtained from the study revealed that plant height was significantly affected by water stress and compost application. Although there was variation between treatments, increase in plant height after planting indicated that water availability and uptake of nutrients significantly increased plant height under irrigated as well as non-irrigated experiments. Xu and Mou (2016) reported that increased growth in-terms of length and biomass accumulation due to compost treatment may be ascribed to increased photosynthesis.

Regarding compost application, the results revealed that the highest measurements were obtained from compost soil and/or in combination of compost soil + urea while the shortest heights were noted from non-compost treatments. This study agrees with the work of Mahmud *et al*. (2016) who reported that the combined application of compost and chemical fertilizer on rice plants had a great influence on plant height which might have been due to the presence of major nutrients from the organic fertilizer combined with the instantaneous readily soluble nutrients from the inorganic fertilizers. Manish *et al*. (2017) also reported that the tallest plant height was observed on the plots treated by vermicompost and cattle manure, whereas the shortest was in the control without this treatments. The application of compost increased plant height in both conditions meaning that compost has the ability to mitigate drought effects on plant height. A similar result was also reported by Mahmud *et al*. (2016), stating that incorporation of vermicompost to the soil influenced plant growth, especially plant height compared to control treatment (non-fertilizer application). Plant height plays a major role in the final yield of maize crops. The increase in plant height with compost addition can be attributed to that compost promotes plant growth, increases the number and length of the internodes which results in progressive increase in plant height. The findings are also in agreement with the work of Aziz *et al*. (2010) and Ogbonna *et al*. (2012), who both reported a significantly taller plants and larger leaves with compost application. According to Okoroafor *et al*. (2013) the application of organic manure highly increased plant height, number of maize leaves, stem girth, number of cob and weight of fresh maize at harvest. Similar results were reported by Coulibaly *et al*. (2019) who found that the tallest growth parameters of maize were obtained with compost made from pig's manure. Generally, it was observed that treatments that received both compost and urea fertilizer produced taller plants compared to plants in control treatments.

Concerning drought stress effect, this study showed that compost amendment into the soil increased water availability to the plants under stressed condition and accelerated recovery of plants after drought stress. It was observed that low water availability suppressed maize plant height during the experimental study. The results depicted a varying range of plant height under well-watered and stressed conditions. Well-watered maize plants were taller, yet again taller plants were also observed under drought stressed condition on plants treated with SC and SUC, and the results can be associated to the fact that the incorporation of compost added organic sources into the soil which improved soil water holding capacity. This agrees with the work by Logsdon *et al.* (2017) who examined the water content of lawns with compost incorporation. Similar finding was stated by Mahmood *et al.* (2017), who reported that organic manure application decreased soil bulk density and enhanced soil porosity and water holding capacity. Compost is known to have a high water holding capacity and can provide water to plants over time (Crogger, 2005). Drought stressed plants had significantly reduced plant height as compared to well-watered treatments. So it is clear that plant height is negatively affected by drought stress. According to Sikuku *et al*. (2012) the depression of plant height could also have resulted from a reduction in plant photosynthetic efficiency. Studies have shown that the decrease in transpiration rate under drought stress significantly decreases plant height and dry matter content (Ramegowda *et al*., 2014). Drought stress induced reduction in plant height was also observed by Khan *et al.* (2014) in soybean.

5.3.2 Stem diameter

Stem diameter of maize is an important measure, which determines its strength and ability to resist to lodging. It was observed that under reduced water supply the stem becomes thinner and furthermore the increase in stem diameter due to compost amendments can be elucidated by the fact that compost promoted plant growth. The results revealed that main stem diameter of maize planted in SC and combination of SUC tend to have thicker stems as compared to those planted in control and SU treatments under both treatments. Control and SU plants resulted in the lowest stem diameter, which can be described as a direct effect of nutrient availability. Results of this trial are in line with several earlier work of (Ravi *et al*., 2012; Lone *et al*., 2013). The increase in stem diameter indicated improved growth of maize plants after the addition of composts to the soil. Organic manures have been said to improve soil fertility by activating soil microbial biomass, which in turn leads to development in crops (Ayuso *et al.*, 1996) and this may have been responsible for the observed increase in stem diameter resulting from nutrient application. Comparable results were obtained by Haouvanga *et al.* (2017) who stated that adding compost on soil significantly increased the number of leaves and the stem diameter of Moringa oleifera. Previous studies also stated that nitrogen significantly increased cereal leaf area. Positive effects of compost may be attributed to providing available source of carbon and nitrogen for soil microorganisms which enhances soil structure, reduces soil erosion, lowers the temperature at the soil surface and helps increase water holding capacity of the soil.

5.3.3 Number of leaves

In this study the number of leaves per plant was significantly affected by water treatments which caused a reduction in leaf number under drought stressed condition. Again in the present experiment averages of 12 and 10 numbers of leaves were formed in maize under irrigated and drought conditions respectively. A study by Lamm *et al*. (2005) found that deficit irrigation reduced total number of leaves. With regard to amendment of compost (SC and SUC) the number of leaves per plant improved significantly when compared with the control treatments. The results of the experiment agreed with the work of Adamu *et al. (*2015), who also reported that application of full farm yard manure, N and P produced the highest leaves per plant, while the control had the lowest leaves. However, Sagar and Sharma. (2015) reported that application of farm yard manure and nitrogen did not significantly influence the number of leaves per plant. The results of the study (Manyuchi *et al*., 2013) reported that vermicompost application increases the number of leaves of maize plants. The number of leaves on a plant determines the photosynthetic activity of a plant which influences growth and yield of the crop.

5.3.4 Leaf area (cm^2)

Combination of compost with urea fertilizer in the trial showed great potential to increase the leaf area of individual plant compared to that of control under both conditions. This explained that different nutrient release from urea and compost improved the chemical and physical properties of the soil thereby increasing the growth and yield parameters of maize. Reduction in leaf area is morphological parameters for measuring drought stress experienced by the plant (Ku *et al*. 2013). Thus decline of leaf area significantly affects maize productivity, due to its low plasticity. Moreover, reduction in leaf area is a mechanism used by plants to avoid higher rate of transpiration and reduce surfaces for radiation due to water deficit (Hayatu, 2014). In general drought stress significantly reduced the total leaf area. Khan *et al*. (2014) in soybean and Samson and Helmut (2007) **i**n cowpea reported earlier that water deficit stress reduced significantly the total leaf area. The results of this study agrees with those found by Muhammad and Jan (2016) who revealed that compost amendment enhanced maize crop yield and yield components.

5.3.5 Days to 50% flowering

During the study period it was observed that maize plants grown under combination of SUC delayed tasseling, while under other treatments tassel emergence was earlier. Delayed tasseling due to compost treatment could be associated with vigorous and prolongs vegetative growth as a result of higher nutrient availability. The results were supported by Li and Cai (2003) who concluded that tasseling in maize was delayed when compost was applied. Dolan *et al*. (2006) also found that compost incorporation had delayed tasseling, which might be due to more fertilizer availability and improved soil condition and fertility. Imran *et al.* (2015) stated that increasing nitrogen level consistently increased days to 50% tasseling due to prolonging the vegetative growth period. Another observation made was that at 11th week after emergence some plants from all treatments had tasseled while maize plants in control and urea treatments were already shedding pollen. According to Carvaco *et al*. (2003) in maize, tasseling normally occurs 2 to 3 days before silk emergence and this varies between genotypes. Various studies (Zamir, 1998; Modarres *et al*. (1998); Gozubenli, 2001) reported that variation in tasseling and silking period of maize hybrid is due to its genetic makeup.

Furthermore the results indicated that days to silking was delayed by compost application and drought stress. Maize planted in SC and SUC treatments had prolonged silking stage ranging between 59- 60 days as compared to control treatments. This could be explained that N content in compost lengthened the vegetative growth period. These results are in line with the findings of Dolan *et al*., (2006) who reported that compost application had delay silking in maize.

5.3.6 Days to 90% physiological maturity, yield and yield components.

With respect to maturity, the number of days required for 90% maturity was influenced by the interaction of water deficit and compost. Application of compost (SUC) caused delayed (120 days) physiological maturity under irrigation condition and early (117 days) to physiological maturity were observed under control treatment under drought stress. In accordance with Bekele *et al*. (2018), physiological maturity in maize was significantly prolonged by applications of lime, vermicompost, and chemical P fertilizer. The result of this study does not agree with the findings of Hegde and Dwivedi (1993) who found that integration of organic manure with inorganic fertilizers were observed to hasten maturity period of the potato crop. This could be described that crop response to fertilizer application depends on the morpho-physiological characteristics, species, cultivar and the rate of application.

5.3 7 Maize biomass production.

Water deficiency imposes limitations on production of biomass by plants. In this study, these limitations were primarily observed in plants subjected to water stress and that were not supplemented with compost. The results demonstrated that the shoots, roots and total biomass yield of maize was negatively affected by water-deficit stress and fertilizer amendments, while these characteristics were significantly increased by the application of compost under both conditions. This results agrees with the work of Nazarideljou and Heidari (2014) who reported that reduction in growth and productivity is a common response of many crop to water deficit. The findings are also in agreement with the results from El-Mageed *et al.* (2018), who reported a significant increase in sorghum shoot biomass after compost addition to a sandy loam, in both water stressed and unstressed conditions. Recently, Zhang *et al*. (2020) demonstrated increased growth and biomass production in cotton due to organic fertilizer through modification of root length, volume and surface area. Kibunja *et al*. (2010) also observed that total biomass of maize was higher in treatment combination of organic and inorganic fertilizer.

Plants that were grown under non-stressed water condition had the highest shoot, root and total biomass yield compared with those that were planted under stressed condition. Generally, the results in this study were consistent with a published data by Abbas *et al*. (2018), which report a decrease in wheat growth and biomass under water stress conditions. The reduction in yield of plants irrigated at four days interval indicates that these plants were subjected to water deficit stress and yield decreasing may be explained by effect of water deficit stress (Bouazzama *et al.*, 2012; Dhakar *et al*., 2018). The parameters examined exhibited similar trends, where the highest values were attained from plants with compost application and full irrigation as comparable with control under both experiments. Compost application is one of the important practical measures to enhance seed yield under water stress condition as reported by EL Sabagh *et al*. (2015b). The results obtained from this experiment could be associated to the fact that addition of compost significantly alleviated the negative impacts of the drought stress. Such trend was consistent with the trend observed for other plant growth parameters. Irrigation water applied at the beginning of the intensive vegetative growth stage increased the process of biomass accumulation. The adverse effect of drought on dry matter accumulation appeared to be significant during tasseling stage. Similar result was also observed by Alghabari and Isham, (2018) that drought stress affected barley yield through impaired grain development and grain filling duration. Serious decreases have been recorded for control and SU plants under both conditions. According to Amanullah *et al*. (2015), application of compost along with N was found to be the best combination to yield and yield components of maize. Gholami and Zahedi (2019) stated that the reduction of yield, yield component and quality under drought stress could be due to numerous reasons including decrease of photosynthesis efficiency, leaf area, net assimilation rate, and reduction of water and mineral absorption by the root which ultimately decline developmental and vegetative growth.

5.4 Effects of water regime and compost amendment on chlorophyll content, photosynthetic rates and intrinsic water use efficiency of maize crop.

5.4.1 Maize chlorophyll content

In the present study, the application of compost alone or together with urea fertilizer and adequate soil moisture content were very effective in helping maize plants to decrease the detrimental effects of drought stress on leaf chlorophyll content. Soil amended with compost fertilizer (SC and SUC) significantly high chlorophyll content of maize leaves and soil water content under both conditions. In general chlorophyll meter readings of maize leaves responded positively to compost amendment (SC and SUC) in both conditions. This could be ascribed to the fact that compost was able to retain soil moisture. This agrees with the work of EL Sabagh *et al*. (2016a) where it was observed that chlorophyll content of soybean plant decreased significantly under high levels of water deficit conditions. Leaf chlorophyll content is influenced by soil and environmental factors. According to Hosseinzadeh *et al.* (2018) chlorophyll content can be tolerance index to water stress in plants. In addition, the results also showed that with increased drought stress, leaf chlorophyll content decreases and applying compost the leaf chlorophyll content increases. Our results are in line with, Ndiso *et al*. (2017) and Tembe *et al*. (2017) who both reported that drought stress significantly reduced chlorophyll content in cowpeas and tomato, respectively. It was observed from the experiment that compost amendment prolonged the green leaves which basically allows for a longer period of leaf photosynthesis. Overall, the majority of chlorophyll lost from plant leaves subjected to drought stress is lost from the mesophyll cells. Huerta-Pujol *et al*. (2010) went on to explain that the reasons for this preferential loss could be attributed to the fact that the mesophyll cells are farther removed from the vascular supply of water than the bundle sheath cells and hence develop greater cellular water deficits which lead to a greater loss of chlorophyll. Chlorophyll content of maize subjected to the compost treatment was significantly higher when comparable with control treatments. This significant increase maybe due to the improvement of the nutritional condition of soil especially N, which reflected on the growth of the plants.

5.4.2 Photosynthetic rates and intrinsic water use efficiency.

In this study, maize under drought stress more especially the control without compost application had considerable reduced photosynthetic rate as compared to irrigated or well watered treatments. During water stress, stomatal closure leads to decreased leaf conductance, photosynthesis and transpiration. Due to the sensitive response of leaf conductance to reduced leaf water potential, the more conservative use of water results in higher WUE in water-deficient plants, which may be a mechanism for improving resource use efficiency (Liu *et al.*, 2016). Photosynthesis is one of the most important physico-chemical processes of higher plants that is directly linked to plant biomass production; however, it is very sensitive to drought stress (Yang *et al.*, 2014). A study by Adugna (2016) proved that plant's photosynthesis rates improved with the availability of soil moisture due to the application of soil organic amendments such as biochar and compost. Stomata closure is an initial response of plants to drought stress (Pirasteh-Anosheh *et al.*, 2016). When roots are exposed to water stress generate the chemical signals such as ABA that send response in the stomatal. Controlling water loss through stomatal closure has been considered as an early response of plants to water stress (Yan *et al.*, 2016, Harb *et al.*, 2010). In this study, under drought condition water use was significantly low resulting in high WUE. Severe decrease in terms of water use was recorded in control treatments indicating that WUE was affected by water stress and WUE decreased with an increase in water stress. This agreed with many previous studies who have found that WUE of various plant species is improved under water stress (Ye *et al.*, 2013). It has been suggested that the drought-induced suppression of photosynthesis could be generally attributed to stomatal limitation and/or non-stomatal/metabolic limitation (Zhang. *et al.*, 2013).

WUE describes the intrinsic trade-off between carbon fixation and water loss, because water evaporates from the interstitial tissues of leaves whenever stomata open for CO2 acquisition for photosynthesis (Bramley *et al*. 2013). It represents the ultimate performance of crop yield and water consumption, and it determines the water saving capacity and water productivity of crops. According to Mashilo *et al. (*2017) WUE is an important physiological adaptation mechanism that can improve crop productivity under conditions of water scarcity.

Furthermore, regarding compost application the results of this study revealed that maize crops sown in compost applied soil and combination of urea + compost were more water use efficient under both conditions. It is evident that applying compost significantly increases WUE and this could be attributed to the subsequent observed higher biomass yield. Consequently, the incorporation of compost treatment resulted increase in WUE compared with non-compost treatments.

5.5 Effects of compost amendments on nutrient content, nitrogen and phosphorus use efficiency of maize.

5.5.1 Nutrient content

This study showed that nutrient content of maize plants under irrigated and drought stress conditions were improved by compost amendment of soil. On the effects of treatments on the nutrient accumulation in the maize plant tissue at final harvest, maize grown on SC, SU and SUC had the highest content of Nitrogen, Potassium and Phosphorous as compared to control treatments and this could be attributed to increased availability of essential plant nutrients content in the soil. Sánchez *et al.* (2017) also reported the highest yield and tissue content of K and P where compost consisting of chicken manure was applied. Moreover, Zhang *et al.* (2016) documented that separate or combined application of bio-char and compost had a significant influence on plant N, P and K content in comparison with inorganic amendments. According to Carroll (2011) the amount of any micronutrient absorbed depends on the plant's response to the nutrient, bioavailability of the nutrient and concentration of the nutrient around the root's surface of the plant.

5.5.2 Nitrogen use efficiency as influenced by compost amendments

The study revealed that enhancing sandy soils with compost significantly affected the agronomic NUE of maize under full irrigation and drought stressed conditions. NUE was significantly higher at treatments where compost was applied with urea fertilizer than where urea was applied without compost and control. Increased NUE as a result of combining compost with urea fertilizer was most likely attributed to the contribution of compost in alleviating other crop growth constraints. According to Souri and Hatamian (2019) it is well known that nutrients uptake and the water available to plant roots are closely related. Li *et al*. (2015) reported that under severe water stress, the photosynthetic capacity of the ear leaf decreased as did the dry matter production capacity, which resulted in yield decreases and limited plant N uptake, which in turn seriously affected N utilization in the plant. The application of organic manures to the soils causes increased in SOM, increased water holding capacity and aggregation stability, resulting in nutrient leaching reductions and improving the nutrient use efficiency (Baligar *et al*., 2001). However, the results of this study does not agree with the findings of Djaman *et al*. (2013), who found that excess of irrigation favors the residual loss of NO_3^-, through either leaching or denitrification, due to its high mobility in soil under high moisture conditions, causing a reduction in the efficiency of N use for production. This is supported by Gholamhoseini *et al. (*2013) findings that higher N responses in maize yield under favorable soil water conditions, with an increase in reduced water regime under semiarid conditions. Plants take up N in the form of $NH4^+$, a result of mineralization, and $NO3^-$, a result of nitrification. As mentioned, compost as an organic source when incorporated into soil results in stabilization of nutrients against volatilization and leaching hence continual nutrient availability to the plants.

5.5.3 Phosphorus use efficiency in maize as influenced by compost amendments.

This study indicated that PUE increased with available water and was generally greater for compost treatments, especially under irrigation condition as comparable to stressed condition. Increased PUE during the study period could be linked mainly to water availability to the maize crop grown under unstressed experiment. This work agrees with Qin *et al*. (2005), who detailed that the diffusion process, as a result of which phosphorus is carried towards the root, occurs faster in a moist rather than in a dry environment. This result indicated that optimizing water and compost application improved the PUE maize. Reductions in phosphorus use was observed under water deficit condition. With regard to compost addition, phosphorous use efficiency showed a remarkable result for the combined application of SC and SUC and these findings were also studied by Ademba *et al*. (2015) who reported that integrated use of phosphate fertilizers (inorganic) and manure(organic) applications significantly improved maize yield and PUE. Limitation of grain crop productivity by phosphorus (P) is widespread and will probably increase in the future. Improving the efficiency of phosphorus (P) fertilizer use for crop growth requires enhanced P acquisition by plants from the soil (P-acquisition efficiency) and enhanced use of P in processes that lead to faster growth and greater allocation of biomass to the harvestable parts (P-use efficiency (PUE). Phosphorus use efficiency in plants is a complex trait that is controlled by both P uptake, or P acquisition efficiency, and P utilization efficiency Mendes e*t al*., 2014; Manschadi *et al*., 2014).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The study verified that compost applied alone or in combination with chemical fertilizers offers potential to enhance soil quality and improve crop yield. Among all treatments, SC and SUC treatments showed potential as a soil conditioner, which directly improved soil physicochemical features such as soil pH, EC, CEC, TC, TN, available P and exchangeable cations under any condition.

6.1.2 Hypothesis that compost amendment under drought stressed condition is the key factor to retain soil moisture and increase the productivity of maize crop has been confirmed by this study. Compost efficacy on morph-physiological indices of maize under both well watered as well as stressed condition has been observed in this study.

6.1.3 Among all the treatments studied, SUC (soil + compost +urea) treatments greatly increased nitrogen use efficiency of maize (NUE) as compared to SU (soil +urea), SC (soil + compost) and control treatments recorded lower value under water deficit and well watered conditions.

6.1.4 From the above obtained results, SC (soil compost) and SUC (soil +compost + urea) had the highest phosphorus use efficiency (PUE) whereas SU (soil + urea) and control treatments recorded the lowest values in both conditions. It can then be concluded that compost amendment has effect on PUE.

6.1.5 The current study proved that compost amendments is the best approach to overcome drought stress effects on maize crop. The results revealed that soil + compost (SC), soil+ urea (SU) and soil +compost +urea (SUC) and control treatments had the highest values under irrigated condition although under drought stressed condition control treatments exhibited the lowest value. Finally it is concluded that amending soil with compost is a good strategy to promote water use efficiency (WUE) and therefore, it is considered useful under stressed conditions.

6.2. Recommendations

6.2.1 Further studies should be on soil-crop modelling as a tool for understanding the collaborative effects between water and nutrient use in yield, WUE and NUE, and for improved managing approaches.

6.2.2 There is a need to evaluate the response of different varieties of maize to confirm genotypic variation in water use efficiency and nutrient use efficiency under rain-fed environment.

6.2.3 Further research studies should include compost in evolving nutrient response curves, for various cereals crops under rain-fed conditions.

6.2.4 Investigations should be done on the prolonged existence of compost in various soil textural class after one application under rain –fed condition.

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