Effects of Nitrogen and Phosphorus Fertilizers on Growth, Yield, and Yield Components of Sorghum (*Sorghum bicolor* (L) Moench)

Masters of Science (MSc) in Crop Science (Agronomy)

By
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EFFECTS OF NITROGEN AND PHOSPHORUS FERTILIZERS ON GROWTH, YIELD, AND YIELD COMPONENTS OF SORGHUM (*Sorghum bicolor (L) Moench)*

A dissertation presented to the Department of Crop Science and Production in partial fulfillment of the requirements for the Degree of Masters of Science (Msc) in Crop Science (Agronomy)

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STATEMENT OF ORIGINALITY

The work contained in this dissertation was compiled by the author at the University of Botswana's Botswana College of Agriculture between 2010 and 2013. It is original except where references are made and it will not be submitted for the award of any other degree or diploma of any other university.

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DEDICATION

This work is dedicated to my family for being so supportive throughout my study and to my work supervisors for allowing me to study while my duty suffers. To all people out there, this is to show that being born from a family with low level of education does not mean you too you are going to be un-educated, you can be a professor, just try it and see that the sky is the limit.

ABSTRACT

Greenhouse and field experiments were conducted during the 2009 and 2010 growing seasons at Botswana College of Agriculture to evaluate the effect of different levels of nitrogen (N) and phosphorus (P) fertilizers on growth, yield and yield components of sorghum. Experimental treatments for both greenhouse and field experiment consisted of factorial combinations of four rates of nitrogen (N) and four rates of phosphorus (P) making a total of 16 treatments replicated three times. The N rates in the greenhouse study were 0, 100, 200 and 400 kg N / ha whereas in the field experiment the rates were decreased to 0, 50, 100, 150 kg N / ha. Similarly the P rates for the greenhouse study were 0, 50, 100 and 150 kg P / ha whereas in the field the rates were decreased to 0, 12.5, 25 and 37.5 Kg P / ha. Application rates of 100, 200 and 400 kg N ha^{-1} in the greenhouse significantly affected plant height, biomass, nitrogen content and protein content as compared to 0 kg N ha^{-1} whilst application rates of 50, 100 and 150 kg P ha^{-1} affected plant height, number of leaves, biomass and phosphorus content of sorghum significantly. Interaction of nitrogen and phosphorus gave significant results in plant height and biomass. From the greenhouse experiment it as was concluded that application of N and P fertilizer increase yields of sorghum. This suggest that farmers can apply fertilizer when growing sorghum. If this research is repeated, researchers should allow sorghum to produce grain so as to find out if the yield will be significantly different between the control, N and P application rates.

In the field experiment, N had no significant effect on grain yield, biomass, weight of 1000 seed, root weight, number of tillers per plant and flag leaf area. However, increasing N from 0 to 50 kg / ha increased grain yield, head weight and tissue N content were significantly affected by application of N. Field experiment did not produce significant results in most parameters measured.However it is recommended that the rate of 50 kg N ha^{-1} be recommended to farmers in their field since it increased grain yields. This research needs to be carried out in different areas of Botswana because the soil in Sebele is different from the soil in other areas of Botswana.

In the field, same results were obtained with the effect of phosphorus. There were no significant effect on grain yield, biomass, weight of 1000 seed, number of tillers per plant, seed protein content, leaf nitrogen and phosphorus content. However, root weight and leaf area were significantly affected by application of P. Grain yield increased when P was increased to 25 kg / ha therefore it is recommended that farmers should use 25 kg/ ha in their fields.

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LIST OF ABBREVIATIONS

CEC- Cation exchange capacity

EC - Electrical conductivity

DAR – Department of Agricultural research

N – Nitrogen

P - Phosphorus

Ca- Calcium

Mg – Magnesium

P – Potassium

Na - Sodium

CHAPTER ONE

1.0 INTRODUCTION

1.1 General introduction

Sorghum *(Sorghum bicolor (L) Moench)* is an indigenous African cereal grown mainly for human consumption. In West and Central Africa the grain is grounded into flour and used to make thick or thin porridge (Belton and Taylor 2002). Sorghum flour is mixed with water and allowed to ferment for 24 hours before being added to the boiling water and cooked for consumption. It is an important food crop in Botswana (Boiling and Eisener, 1981). Eisener (1977) reported in a survey of the Southern and Southeastern Districts of Botswana that 96% of the people interviewed indicated that they eat sorghum. Of these, 89% eat it daily and the other 11% eat it two to three times weekly. It also plays a major role in the beer industry. The grain is germinated, dried and grounded to form malt which is used as a substratum for fermentation in local beer production (Balole and Legwaila, 2006). Belton and Taylor (2002) explained that in Burkina Faso, Ghana, Mali, Nigeria and Togo traditional beers are brewed with sorghum malt. Similarly in Botswana traditional beers (chibuku) are brewed from sorghum.

Sorghum is also an important crop to livestock as it is used as feeds. In other countries like America and Australia, sorghum is used as an important feed grain and as a fodder crop. The plant stem can be chopped for silage or fed to animals (House, 1985). In developing countries, the leaves and stems are used as building materials and as fuel for cooking (Chantareau and Nicou, 1994).

Sorghum *(Sorghum bicolor (L) Moench)* is grown by subsistence farmers in much of semi – arid areas (Doggett, 1988). In Botswana, sorghum is planted by both subsistence and commercial farmers. In 2003, subsistence and commercial farmers planted 39 187 ha of sorghum and obtained

23 500 metric tonnes of grain yield (Annual Agricultural Survey Report 2003). This shows that sorghum yields in Botswana are low. It seems lack of soil fertilization is one of the factors limiting yields of sorghum in Botswana. Farmers in Botswana do not apply fertilizer when planting sorghum and this results in low yield. Nitrogen (N) and phosphorus (P) are the major elements required by the crop in large amounts. However, deficiencies of N and P in soil of Botswana are common. This deficiencies might be caused by leaching of N, the fact that soils in Botswana lack P, soil erosion and removal by crops. The use of N and P is extremely important if high yield are to be achieved in farmer's fields.

Several fertilizer trials have shown that P and nitrogen N fertilizers can significantly increase yields of sorghum in Botswana. Department of Agriculture Research (DAR, 1977) reported that a combination of N and P fertilizers were necessary to obtain maximum yields. Elsewhere, it has been shown that N and P can increase yield. Ashiono *et al.* (2005) reported that in Kenya 9 tonnes / ha of sorghum grain yield were achieved when application rates of 40 kg N ha^{-1} and 20 kg P ha^{-1} were made. This shows that yields of sorghum in Botswana can be increased to compare well with yields obtained in other countries. These low yields of sorghum in Botswana are probably associated with inappropriate application rates and methods. In Botswana, the recommended application rate of N is 75 kg of Lime - ammonium Nitrate (LAN 28 % N) or 50 kg of Urea (46 % N) which is equal to 21 kg N / ha or 23 kg N / ha. Application rate of P is 200 kg / ha of 2:3:2 (22) which is equal to 18 kg P / ha. These recommendations are deemed to be low therefore a review of this recommendation and determination of correct application rate of N and P in Botswana is essential because of changing rainfall pattern and temperature due to Global warming.

1.2 JUSTIFICATION OF STUDY

Due to increasing human population, the demand for food has increased but food production in Botswana is low. Botswana is faced with a challenge of increasing food production so that the country may be self-reliant in food supply. Self-reliance of food supply will remain a dream if Batswana farmers neglect improvement of soil fertility. Research work done outside Botswana indicates that high sorghum yield can be obtained with N and P application. Kapour *et al.* (2008) reported that compound fertilizers that contain high concentration of N and P produced higher sorghum grain yield and straw yield. Around the 80's in Botswana DAR has also conducted studies in the area of soil fertility and they have reported that combinations of NP and NPK increase yields. Recommended application rates were suggested but they need verification because these are old and not effective because of climatic changes as grain yield in other countries is more than grain yield in Botswana.

This calls for research on the use of chemical fertilizer as a means of improving soil fertility. It has been shown that an important means of increasing food supplies is through the use of chemical fertilizers. N and P fertilization is an important component of soil management. Soils of Botswana are deficient in nitrogen and phosphorus. High sorghum yield can be achieved if the soil are well managed hence this study was designed to evaluate the response of sorghum to N and P in the typical Botswana soil.

1.3 OBJECTIVES

The objective of the study was:

1. To evaluate the effects of N and P application on growth, yield and yield components of sorghum.
2. To determine the effects of interactions of N and P on growth, yield and yield components of sorghum.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Vegetative morphology of sorghum

Sorghum belongs to the family poaceae. Most members of this family are grasses. Sorghum is an annual grass which can grow up to 4 m tall, with one to many tillers. The tillers are influenced by crop variety, plant population and soil fertility. Sorghum varies greatly in height. The height is dependent upon the number of nodes which equals the number of leaves produced. The leaves on the main stem vary in number according to variety. The mature leaves may reach length of 30 – 135 cm, and width between 1.5 and 13 cm at the widest point (Doggett 1988).

2.2 Chemical fertilizers and sorghum

Nitrogen (N), phosphorus (P) and potassium (K) are the essential elements required for plant growth in relatively large amounts. Deficiencies of N and P are common in soils in Botswana thereby reducing yields of sorghum. It has been found that increase in yield is based on correct application methods, time of application and rate of application of fertilizer (Belton and Taylor 2002). Fertilizers can be applied as single or compound fertilizers. Compound fertilizers are better because they supply plants with more than one nutrient usually N, P and K. Murty *et al.* (1994) reported that compound fertilizers such as NPK containing the three major nutrients in the correct ratio should be incorporated into the soil as basal application prior to sowing to increase yields of sorghum.

There are variations in response of sorghum to chemical fertilizers. The type and quantity of nutrients required by sorghum plant depend on many factors. The most important factors are genotype, initial soil fertility status, soil pH, moisture and plant density. Murty *et al* (1994) reported that the quantity of nutrients required increases with increasing plant density as there are more plants competing for available nutrients.

2.3 Effect of N and P on growth and development

N is important in the formation of proteins, nucleic acids, and synthesis of chlorophyll in sorghum plants (Murty *et. al.*, 1994). Lea and Gaundry, (2001) explained that abundant N supply increases the number of meristems produced by sorghum plants and their growth thus encouraging shoot (branches and tillers) formation and growth. Amed *et al.* (2007) reported that exposing sorghum plants to N stress at any phase of its life cycle might lead to detrimental effects on growth, yield and its components. The deficiency of N results in stunted growth, chlorosis of lower leaves as N is translocated to newer developing leaves. Yellowing proceeds from the leaf tip and spreads to the base and then to the leaf margin (Murty *et al.*, 1994), (Tisdale *et al.*, 2005).

In sorghum plants, P has a major role in energy transfer, cell division, formation of fat and root development. The energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds for use in growth and reproductive processes (Tisdale *et al.*, 2005). In cereal crops, P enhances crop maturity, increases straw strength and reduces the time required for grain ripening. The deficiency of P is characterized by delayed maturity, reduction of harvest index, and poor development of the root system, stem and leaves (Murty *et al.*, 1994).

2.4 Effect of N and P on grain yield and yield components of sorghum

Application of N increases dry mater yield, grain yield and grain N content (Roy and Wright 1972). These researchers reported that application rate of 60 kg N ha^{-1} increased grain yield and grain N genotype, initial soil fertility status, soil pH, moisture and plant density. Murty *et al.* (1994) reported that the quantity of nutrients required increases with increasing plant density as there are more plants competing for available nutrients.

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According to Ashiono *et al.* (2005), N and P levels beyond 40 and 30 kg ha^{-1} respectively did not increase plant height, seed weight, crude protein and grain yield. The highest sorghum grain yield was attained at combination of 40 kg N ha^{-1} and 20 kg ha^{-1} P_2O_5. Optimum crude protein was obtained at 20 N and 30 P kg ha^{-1}. However, other researchers found lower grain yield of sorghum at similar N application rates (Buah and Mwinkaara, 2009).

Nitrogen deficiency can result in reduced dry matter production and grain yields. Sorghum responds to applied fertilizers and can increase yield by over 50%. Sorghum responds more to fertilization on soils with low fertility than on soils which are highly fertile. Recorded yields ranging between 20 kg and 40 kg of grain per kg of applied N have been reported by House (1995).

Response of sorghum to N and P application rates may be affected by water stress. Khalili *et al.* (2008) working on sorghum under limited irrigation and phosphorus found that by limiting water and phosphorus fertilizer, grain yield will decrease. Least yield of less than 500 kg/ha was achieved during severe water stress and sole ammonium phosphate (250 kg/ha). The highest grain yield of 7000 kg/ha was obtained from the control irrigation treatment (no drought stress) when biological phosphorus fertilizer was applied along with 50% of the required ammonium phosphate.

Ogunlela (1988) investigated growth and yield response of dryland grain sorghum to N and P fertilization. The results showed that grain and straw yields and yield components were enhanced by N fertilization. N and P enhanced grain weight per head, grain number and tillering significantly. Almodares *et al.* (2009) found significant increase in biomass yield due to application of nitrogen.

In Botswana, Department of Agriculture Research (1977) reported that fertilizer combinations increased yields of sorghum. Application of both N and P (at 50 kg / ha each) produced the highest grain yield of 1424 kg/ha followed by NK with 1403 kg/ha suggesting application of N and P together was more effective than single fertilizers.

Grain yield response of sorghum may be affected by the methods of fertilizer application. Reddy *et al.* (2008) concluded that for obtaining maximum yields in sweet sorghum, an optimum dosage of 64 N ha^{-1} (half as basal and half as top dressing) can be applied. Highest grain yield of 8.53 t ha^{-1} was obtained when N was applied as basal and top dressing.

Akram *et al.* (2007) evaluated the growth, yield and nutrient uptake of sorghum in response to intergrated P and K management. The results indicated that P enhanced the crop growth, yield and nutrients uptake more than K and the best results were observed with their combined application. The effectiveness of N and P on sorghum grain yield may be further enhanced by farm yard manure (FYM). Alemu and Bayu (2005) studied the effects of farmyard manure and combined N and P fertilizer on sorghum and soil characteristics in Northeastern Ethiopia and found significant grain yield increase when FYM was applied with mineral fertilizers as compared to application of FYM alone. Combined application of FYM and mineral fertilizer significantly increased stover yield and panicle weight.

The relationship between N supply and dry matter accumulation of sorghum has been reported by Nemeth (2002). The researcher reported that N increased dry matter and grain yield of sorghum. The highest dry matter yield was obtained at an application rate of 240 kg N ha^{-1}.

2.5 Effect of N and P on grain protein content of sorghum

Protein content of sorghum is influenced by the efficiency of N uptake and translocation to the seed than by the level and form of N applied to the soil (Hulse *et al.*, 1980). N uptake and transfer efficiency is affected by the time of fertilizer application, rainfall patterns and soil moisture. Nitrogen fertilizers produce a higher grain yields than a higher grain protein content.

Murty *et al.* (1994) explained that N plays an important role in synthesis of grain protein of sorghum seeds. Synthesis of protein in sorghum depends on uptake of soil N. According to Hanna *et al.* (1999), application of N fertilizer increases the seed protein content of cereals. Application of N fertilizer increased seed protein content by 64 % greater than the control. Amed *et al.* (2007) found out that nitrogen affected the protein content of sorghum. There were significant differences in protein content in response to N fertilizer sources. Highest protein content was obtained with ammonium sulphate than with urea. Similar results were obtained by Almodares *et al.* (2009) who reported that N increased protein content of sorghum significantly.

2.6 Effect of soil type on response of crops to N and P

Hassan *et al.* (1972) reported that soil with high salinity decreased dry matter production of cereals. Uptake of P, K Ca, Fe and Cu was decreased by high salinity level while uptake of Mg, Zn, Mn, and Na increased with increase in salinity. Macronutrient and micronutrient availability are affected by soil pH. In slightly to moderate alkaline soils, molybdenum and macronutrient (except for phosphorus) availability is increased. Dissolved N will have the highest concentrations in soil with PH 6 – 8. Concentrations of N are less sensitive to PH than concentrations of available P. In order for P to be available for plants, soil PH needs to be in the range 6.0 – 7.5 (Soil survey division staff 1993).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

Greenhouse and field experiment were conducted at Botswana College of Agriculture located at Sebele in Gaborone, Botswana, from 2009 to 2011 to evaluate the response of one variety (segaolane) of sorghum to N and P. The experimental site (Sebele) is situated at latitude 24^{0}'33 S and longitude 25 ^{0}'54 E and has altitude of 994 m above sea level. The climate in Sebele is semi-arid with an average rainfall of 538 mm (Berker and De Wilt, 1991). Summer rainfall start in late October and continues to March / April. Soils are shallow, with ferruginous tropical soils, mainly consisting of medium to course sand and sandy loam. Soils with low water holding capacity and subject to crusting after heavy rains. These soils are deficient in P and low levels of N and organic matter.

Prior to both experimental set up, soil samples were taken from the field for physical – chemical analysis. Soil used for greenhouse experiment was collected from a field at Molepolole. Soil samples were taken with the aid of a spade at an intervals of 5 m across the field at a sampling depth of 0.15 cm. The soil samples for all units were mixed into one composite sample. The soil was air – dried and screened through a 2 mm sieve. A subsample was taken to characterize the soil physical – chemical properties.

3.2 Characterization of soil used in the experiments

3.2.1 Particle size analysis

The particle size analysis was determined by the hydrometer method as described by Gee and Or (2002). The procedure followed were that 50 g of soil was weighed into plastic bottle to which 25 ml of cologne (sodium hexametaphosphate) and 400 ml of water were added. The soil was shaken on a mechanical shaker. The soil suspension was transferred to 1 litre cylinder and diluted to the mark with tap water. The suspension was stirred and one hydrometer was inserted to take the readings at the following time intervals. The first reading was taken after 4 minutes and 48 seconds to determine silt and clay. A second reading was taken after 5 hours to determine clay.

3.2.2 Organic matter determination

The organic matter of the soil was determined by the dichromate oxidation method as described by Nelson and Sommers (1982). One gram of finely ground sample was weighed into 250 ml conical flask to which 10 ml of potassium dichromate (K2Cr2O7) solution was added. The flask was swirled to disperse the soil in the solution and 20 ml of concentrated sulphuric acid was added and then mixed with the soil. The flask was allowed to stand for 30 minutes to cool down before adding 200 ml of water. The soil suspension was filtered through Whatman No. 1 paper and titrated with 0.5 M ferrous ammonium sulphate solution ($NH_4SO_4.FeSO_4.6H_20$) using ferroin as an indicator. The organic matter in the soil sample was calculated by multiplying organic carbon by 1.72 (Nelson and

Sommers, 1982). The organic carbon in the soil was calculated as : (meq of Cr_2O_7 - meq fe-NH4-SO4) * 4

weight of soil sample

3.2.3 Soil pH determination

The soil P^H was determined using $CaCl_2$ solution method. 10 g of soil was weighed into a 50 ml beakers and 20 ml of 0.01 $CaCl_2$ solution was added. The solution was stirred with glass rod and the soil suspension was allowed to stand for 30 minutes. Soil pH was determined by immersing the glass electrode (model - Hanna pH 210) into the settled soil suspension.

3.2.4 Electrical conductivity (EC)

The EC of the soil was determined from saturated paste extract using conductivity meter. To 10 g of soil weighed into plastic cups, 30 ml of water was added. The mixture was shaken for 40 minutes and allowed to settle until extract was clear. The EC was measured by conductivity meter, model cybersan CON 1500.

3.2.5 Cation Exchange Capacity (CEC)

The CEC of the soil was determined by the acetate ammonium solution method Rhodes (1982). The soil was leached with ammonium acetate at pH 7.0 to remove exchangeable cations from exchange sites and to saturate these sites with ammonium ions. The exchangeable ammonium was removed by the usual Kjeldal distillation and titration as described by Mulvaney (1982).

3.2.6 Available phosphorus

The available phosphorus was determined by the Bray – 1 method. To 3 g of soil added to 50 ml extracting cups, 30 ml of Bray extraction solution was added and then stirred for 40 seconds. The suspension was filtered through whatman No 1 into dry clean plastic cups. 5 ml of the extract and of the standard solution was pipetted in a 50 ml dry clean plastic cups. 20 ml of the colour developer was added to both the extract and standard solution. The absorbance was determined using UV spectrophotometer. Calibration curve was drawn and the concentrations of the samples were read from the graph.

3.2.7 Determination of total nitrogen

Total N was determined by digestion of soil in oven. Fine ground sample was weighed into digestion tubes. Two blanks and reference samples were included. To each digestion tube containing soil sample, blanks and reference sample, 20 ml of concentrated sulphuric acid (H_2SO_4) was added to the tubes. The tubes were placed in the heater and heated for 1 hour at a temperature of 200 0C. After one hour the tubes were allowed to cool and 4 ml of hydrogen peroxide was added and the tubes were heated at a temperature of 330 ^{0}C until the soil suspension was clear. The tubes were allowed to cool and 10 ml of distilled water was added to the tubes. Nitrogen in the digest was determined by the kjeldahl distillation method described by Mulvaney (1982)

3.3 GREEN – HOUSE EXPERIMENT

Greenhouse experiment was carried out at Botswana College of Agriculture using sandy soil collected from Molepolole village. This pre- experiment was done to study the effect of N and P on sorghum under controlled condition before trials were taken to the field.

3.3.1 Experimental design and treatments

The experimental design for this experiment was a completely randomized design with three replications. The treatments consisted of a factorial combination of four levels of N (0, 100, 200 and 400 kg N ha^{-1}) and four levels of P (0, 50, 100 and 150 Kg P ha^{-1}). (4x4x3). Urea was the source of N while the source of P was single superphosphate. The appropriate rates of N and P were thoroughly mixed with 10 kg of soil on a clean bucket and returned to the polythene bag. Ca, Mg K, Zn, Cu and Mn were dissolved in water and applied to all pots to make the soil rich in other nutrients that are needed by the plants. The pots were watered to field capacity and allowed to equilibrate for 24 hours before sowing. The composition and application rate of nutrient solution are given in Table 1a.

3.3.2 Planting and management practices

Twenty four uniform size sorghum seeds of the Segaolane variety were sown in each polythene pot and later thinned to eight plants per pot after germination and seedling emergence. Watering was done regularly to alleviate any possible water stress on the plants.

3.3.3 Data collection

The plants were harvested after 35 days of the growing period. Plant height was measured from ground level to the tip of the longest leave with the aid of meter ruler, the number of leaves were counted. Before harvesting, the soil in the pot was watered to make it easy to remove the plants with their roots. During harvesting, three plants were cut and taken to the laboratory for measurement of the following parameters: dry matter weight, nitrogen content, protein content and phosphorus content. The plants were oven- dried at a temperature of 72 ^{O}C for 24 hours to determine their dry matter weight. After determining dry matter weight, the plants were grounded and then digested for analysis of nutrients composition.

3.4 Methods used for plant analysis to determine plant nutrients

3.4.1 Determination of N and P in plant shoot

N and P in plant shoot were determined by digesting plant in an oven. 2.5 g of grounded plants was weighed into digestion tubes, two blanks were included. 20 ml of concentrated sulphuric acid was added to the tubes. The tubes were placed in the heater and heated for 1 hour at a temperature of 200 ^{0}C. After one hour the tubes were allowed to cool and 4 ml of hydrogen peroxide was added and the tubes were heated at a temperature of 330 ^{0}C until the mixture was transparent. The tubes were allowed to cool then the digestion material was transferred to 200 ml volumetric flasks. The volumetric flasks were then made to the mark with distilled water. Nitrogen in the plant digest was determined by the kjeldahl distillation method (Mulvaney , 1982) while phosphorus in the plant digest was determined by Morphy and Riley (1962). The plant tissue protein was calculated as % N in tissue multiplied by 6.25 (Jones 1941).

Table 1a : Source and amount of micro-nutrient added to the soil used in the greenhouse before planting

Source	Nutrient	Rate (µg g-1)
$CaCl_2$	Ca	550
$MgSO_4$	Mg	820
K_2SO_4	K	125
$ZnSO_4.7H_2O$	Zn	10
$CuSO_4.7H_2O$	Cu	4
$MnSO_4.7H_20$	Mn	25

3.5 FIELD EXPERIMENT

3.5.1 Experimental Design

The experimental design for this study was a factorial combination of 4x4x3, laid in a randomized complete design with three replication. The treatments for this experiment were factorial combination of four application rates of N (0, 50, 100 and 150 Kg N/ha) and four application rates of P (0, 12.5, 25 and 37.5 Kg P/ha). The source of nitrogen was Urea (45 – 46 % N) while phosphorus was applied in the form of Single Super Phosphate (10.5 %).

3.5.1 Land preparation and fertilizer application

The land was ploughed, harrowed and finally leveled then plots were demarcated. The size of the plot was 4 m by 4m. Planting rows were made with intra row spacing of 75 cm and inter row spacing of 30 cm. Three seeds of segaolane were placed at a depth of 5 cm at each planting station.

Phosphorus was applied at varying levels according to the experimental rates. Nitrogen was applied in two equal doses. One half of the proposed application rates was applied with phosphorus during planting and another half was applied at 30 Days After Planting. All fertilizers were placed 5 cm away from the plant rows.

3.5.2 Management activities

The plots were irrigated during the first two weeks after planting to increase germination. After seedling emergence irrigation was stopped and the plants were rainfall dependent. All other management practices such as weeding, cultivation and pests control were done regularly to provide conducive environment for sorghum plants. One person was employed to chase birds which were coming in large numbers to the plants. Heads of ten plants from each plots were covered with a brown paper to reduce yield loss due to birds. After five weeks, number of tillers were counted and all tillers were removed to reduce competition for nutrients with the main stem.

3.5.3 Data collection

Data collection started after all doses of fertilizer (nitrogen and phosphorus) were applied. Total dry matter was determined after plants reached maturity stage. The above ground plant parts (stems) were harvested, chopped into small pieces and oven dried at a temperature of 60 - 70 ^{0}C for 24 hours. Dry matter was taken from eight sorghum plants. Leaf area was measured using a leaf area meter. Ten plants were chosen from all plots and the third leaf from the top was sampled to determine their area.

When analyzing for mineral content, (N and P) the flag leaves were harvested during flowering. The leaves were oven dried at a temperature of 72 ^{0}C for 24 hours and then grinded using grinding machine. They were digested and analysed for N and P.

3.5.4 Final harvest

Head harvesting was done at 112 days after planting and this was the time when the grain was fully mature and dry. Plant heads were separated from the stalk using knife and they were placed in brown paper. Ten heads were weighed and averaged to determine the average weight of a head. The heads were threshed manually and winnowed. All grains were kept according to their treatments and weighed to determine grain yield. Average yield per heads was converted to yield per hectare by multiplying plant population per hectare by the average yield of one head. The formula below was used to determine plants per hectare.

Plants per hectare = 10 000 sq m / plant spacing in sq m

One thousand seeds were counted and weighed to determine their weight. The seeds were grounded, digested and analyzed to determine the protein content of the grains. Methods for digestion are explained in greenhouse experiment. Grain protein were calculated from the percent N concentration in grain multiplied by a conversion factor of 6.25.

3.6 Statistical analysis

The analysis of variance was carried out using general linear model (PROC GLM) procedure of Statistical Analysis System (SAS Institute, 1996). All statistical comparisons were made at the $\alpha = 0.05$ probability level using the orthogonal contrast.

CHAPTER FOUR

4.0 RESULTS

4.1 Physical and chemical properties of soil use for experiments

The selected physical and chemical properties of soil used in the green house and field experiment are presented in Table 1 b. The soil used for the green house experiments and field experiments were slightly acidic with pH of 5.2 and 6.3 respectively. Analysis of soil showed that soil used for green house study was 92 % sand and of soil used for field experiment was 78 % sand. This indicates that soil used for green house experiment was a pure sand while soil used for field experiment was sandy loam. Both soil used in this experiment were low in organic matter, available P, and other micro – nutrients. The soil used for green house study was low in total nitrogen (158.48 Kg/Ha) while soil used in field experiment contained 580.00 kg/ha of nitrogen.

Table 1 b: Selected physical and chemical properties of soil used in greenhouse and field experiment

Properties	Green house soil	Field experiment soil
Sand	92 %	78 %
Silt	3 %	5 %
Clay	5 %	17 %
Ph ($CaCl_2$)	5.2	6.26
Organic matter	7.36 g kg^{-1}	7.21 g kg^{-1}
Available P	2.04 kg / ha	8.60 Kg / ha
CEC	1.68 c mol kg^{-1}	2.81 cmol kg^{-1}
EC	0.157 ds/m	0.682 ds/m
Available N	158.48 kg / ha	580 kg / ha
Ca	-	924.0 cmol kg^{-1}
Mg	74.4 cmol kg^{-1}	19.2 cmol kg^{-1}
Na	-	12.2 cmol kg^{-1}
K	10.3 cmol kg^{-1}	44.6 cmol kg^{-1}

4.2 The effect of N and P on growth components of sorghum

Plant height

The effect of N and P fertilizer on plant height of sorghum grown in the greenhouse is presented in Table 2. The results show that the application of N and P fertilizer significantly ($P<0.05$) increased the height of sorghum plants compared to the control. All application levels of nitrogen and phosphorus resulted in plant height that was higher than that of the control. The highest plant height of 43.91 cm was achieved in application rates of 400 kg N ha^{-1}. Application of phosphorus at the rate of 100 kg P ha^{-1} gave the highest plant height of 49.46 cm followed by 150 kg P ha^{-1} with 49.45 cm. Plant height between application rates of 100 kg P ha^{-1} and 150 kg P ha^{-1} was almost similar but higher than the plant heights obtained in the rate of 50 kg P ha^{-1} and the control. These results also showed that plant height had significant linear and quadratic relationships at all levels of N and P.

Number of leaves

The different rates of N fertilizer did not significantly affect the number of leaves of sorghum plant grown in the greenhouse (Table 2). However, all application rates of P fertilizer significantly ($P<0.05$) increased the number of leaves per plant over the control. Highest number (7.04) of leaves was produced by an application rate of 150 kg P ha^{-1}, this number of leaves was higher than the control number by 2.71 leaves. Number of leaves obtained in application rate of 50 kg P ha^{-1} and 100 kg P ha^{-1} were similar but higher than the control.

Biomass

Application of N and P fertilizers significantly ($P<0.05$) increased sorghum biomass over the control (Table 2). The highest biomass of 2.11 g (at 5 weeks after emergence) was produced by the application rate of 100 kg N ha^{-1} and this was higher than biomass yield obtained in the control, 200 and 400 kg N ha^{-1}. The biomass obtained in application rates of 200 and 400 kg N ha^{-1} were similar. In P fertilization, application rates of P produced biomass that was significantly ($P<0.05$) higher than that of the control. The highest biomass was achieved in application rate of 100 kg P ha^{-1}. These results also showed that biomass had significant linear and quadratic relationships at all levels of N and P.

4.3 Effects of N and P fertilizers on protein, nitrogen and phosphorus composition of sorghum

Nitrogen and protein content

The effect of N and P fertilizers on plant nitrogen and protein content of sorghum plants grown in greenhouse is presented in Table 2. Application of N fertilizer increased plant nitrogen and protein content over the control, the results were significant at $P<0.05$. Highest plant nitrogen content of 2.9% and protein content of 18.25% was achieved in application of 200 kg N ha^{-1} .

P fertilization did not significantly affect plant nitrogen and protein content of sorghum plants. However, plant nitrogen and protein content were slightly higher than the control at application rate of 50 kg P ha^{-1} and 100 kg P ha^{-1}. There was a positive linear relationship between N levels and nitrogen and protein content of the plant.

Phosphorus content

All application rates of N fertilizer did not significantly affect P content of sorghum plants (Table 2). However, the highest P content of 1.61 ppm was obtained in the application rate of 200 kg N ha^{-1}.

Application of P increased phosphorus content of sorghum plants significantly ($P<0.05$) above the control (Table 2). Highest P content of 1.71 ppm was recorded with an application rate of 150 kg P ha^{-1} and the lowest P content of 1.04 ppm was observed from the control. There were also significant linear and quadratic relationships between phosphorus in phosphorus content of the plant.

Table 2. The effect of nitrogen and phosphorus fertilizer on plant height, number of leaves per plant, biomass per plant, nitrogen , protein and phosphorus content of sorghum grown in the green house.

Treatments	Plant height (cm)	Number of leaves per plant	Biomass per plant(g)	%Nitrogen	%Protein	Phosphorus Content (ppm)
N level (kg N ha^{-1})						
0	32.17	6.08	1.31	2.06	12.89	1.47
100	42.42	6.00	2.11	2.78	16.71	1.45
200	43.86	6.13	1.67	2.90	18.25	1.61
400	43.91	6.33	1.82	2.73	17.11	1.51
	**	NS	**	**	**	NS
CV (%)	7.43	9.62	13.72	23.95	25.21	14.28
SED	1.23	0.24	0.10	0.25	1.67	0.09
N – Linear	**	NS	**	**	**	NS
N- Quadratic	**	NS	**	NS	NS	NS
P level (kg N ha^{-1})						
0	19.04	4.33	0.28	2.48	15.60	1.04
50	44.40	6.45	1.74	2.77	16.70	1.61
100	49.46	6.70	2.46	2.71	17.05	1.68
150	49.45	7.04	2.43	2.49	15.61	1.71
Prob = 0.05	**	**	**	NS	NS	**
CV (%)	7.43	9.63	13.72	23.95	25.21	14.28
SED	1.23	0.24	0.10	0.25	1.67	0.09
P – Linear	**	**	**	NS	NS	**
P - Quadratic	**	**	**	NS	NS	**

**** - Significant at P = 0.05**

NS- Not significant at P = 0.05

4.4 Effect of interaction of N and P fertilizers on plant height and biomass of sorgh plants grown in the green house.

The effect of interaction of N and P fertilizers on height of sorghum plants is shown in Fig The results show that interaction of nitrogen and phosphorus fertilizer had significan increased the plant height of sorghum. The highest plant height of 56.0 cm was recorded interaction rate of 200 kg N ha^{-1} and 100 kg P ha^{-1} while interaction of 0 kg N ha^{-1} and 0 k ha^{-1} gave the lowest plant height of 14.5 cm.

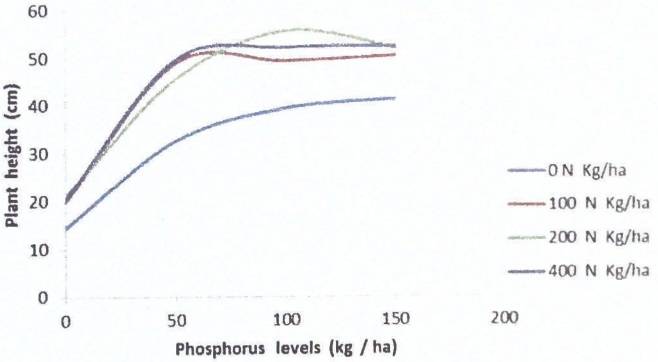

Figure 1. Effect of interaction of N and P fertilizers on the height of sorghum plant

The results on the effects of interaction of N and P fertilizers is presented in Figure 2. T results show that interaction of N and P had significantly increased the production of pl biomass per plant of sorghum. The highest biomass of 2.70g was achieved at interaction of 1 kg N ha^{-1} and 50 kg P ha^{-1}. The lowest (0.16 g) was achieved in interaction of 0 kg P ha^{-1} an kg N ha^{-1}.

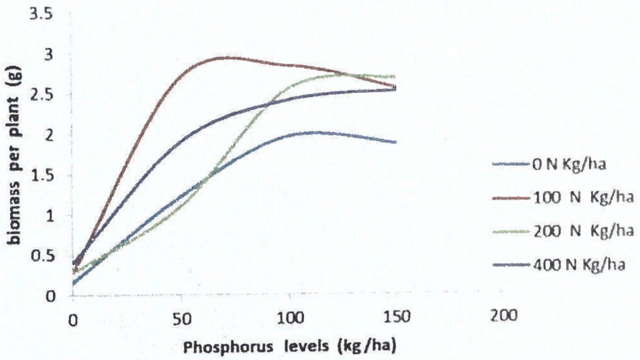

Fig 2. Effects of interaction of N and P fertilizer on sorghum plant biomass

4.5 Effect of N and P interaction on number of leaves, nitrogen content, protein cont and phosphorus composition of sorghum

The results on effect of interaction of N and P on number of leaves, N content, protein cont and P content of sorghum plants are recorded in Table 3. The results show that there was significant increase in parameters measured at all levels of interaction of N and P fertiliz

Highest number of leaves (7.5) was recorded at application rates of 250 N kg/ha and 150 P kg/ha. A slight increase in N and protein content was achieved with application of 400 kg N ha^{-1} and 150 kg P ha^{-1}

Table 3: The effect of interaction of N and P fertilizers on number of leaves per plant and nutrients composition of sorghum plants grown in the green house.

Treatments		**Number of Leaves**	**% Nitrogen**	**%Protein**	**Phosphorus Content (ppm)**
N levels (kg/ha)	**P levels (kg/ha)**				
0	0	4.33	1.56	9.92	1.07
0	50	6.50	2.45	15.33	1.58
0	100	6.67	2.38	14.84	1.56
0	150	6.83	1.38	11.47	1.67
100	0	3.83	2.75	17.12	0.99
200	0	4.83	2.97	18.77	1.08
400	0	4.33	2.65	16.59	1.04
100	50	7.00	3.09	16.70	1.44
100	100	6.33	2.94	18.39	1.72
100	150	6.83	2.33	14.62	1.67
200	50	5.83	3.00	18.79	1.77
200	100	6.33	2.83	18.02	1.95
200	150	7.5	2.78	17.41	1.65
400	50	6.50	2.55	19.98	1.67
400	100	7.50	2.71	16.95	1.50
400	150	7.00	3.01	18.92	1.82
Prob = 0.05		**NS**	**NS**	**NS**	**NS**
CV (%)		**9.63**	**23.95**	**25.21**	**14.28**
SED		**0.48**	**0.25**	**1.67**	**0.09**

**** - Significant at P = 0.05**
NS - Not significant at P = 0.05

4.6 Pictures of sorghum plants grown in the green-house at five weeks after emergence

After five weeks of emergence pictures of sorghum plants were taken to observe any differences occurring in their growth and development (Fig. 3 – Fig. 22). The pictures show that, all plants growing in the control treatment (0 kg N ha^{-1}, with 0 kg P ha^{-1}) were stunted and started to dry up during the firth week. Application rates of N without P did not influence the growth of sorghum plants, see picture 4, and 5. These pictures show that the plants growing in the treatment combinations of 100 kg N ha^{-1} and 0 kg P $ha^{-1;}$ 200 kg N ha^{-1} and 0 kg P $ha^{-1;}$ 400 kg N ha^{-1} and 150 kg P ha^{-1} had the same height with plants growing in the control treatment. However, plants growing in the treatments where P was combined with 0 kg N ha^{-1}, e.g. (0 kg N ha^{-1} and 50 kg P $ha^{-1;}$ 0 kg N ha^{-1} and 100 kg P $ha^{-1;}$ 0 kg N ha^{-1} and 150 kg P ha^{-1}) grew taller than plants growing in the control treatment, see picture, 8, 9 and 10. These pictures showed that combination of N and P influenced the plant height of sorghum. The plants in the treatments which combined N and P were taller and healthier than the plants in the control and in treatments where different levels of N was applied with 0 kg P ha^{-1}.

'ictures of sorghum plants growing in the green house at 5 weeks

'he pictures below show some of the plants growing in all treatments used in this greenl xperiment.

Fig.3. Application rate of 0 kg N / 0 P kg

Fig. 4. Application rate 100 kg N / 0 kg P

Fig.5. Application rate of 200 kg N / 0 kg P

Fig. 6. Application rate 400 kg N / 0 kg P

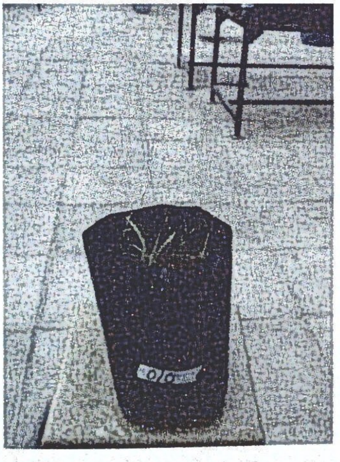

Fig. 7. Application of 0 kg N / 0 kg P

Fig.8. Application rate of 0 kg N / 50 kg P

Fig. 9. Application rate 0 kg N / 100 kg P

Fig.10. Application rate of 0 kg N /150 kg P

Fig. 11. Application rate of 100 kg N / 0 P kg

Fig. 12 Application rate of 100 kg N / 50 kg P

Fig.13 Application rate of 100 kg N / 100 P kg

Fig. 14 Application rate of100 kg N /150 kg

Fig. 15 Application rate of 200 kg N / 0 kg P

Fig. 16 Application rate of 200 kg N/50 kg P

Fig. 17Application rate of 200 kg N/100 P kg

Fig.18 Application rate of 200 kg N / 150 k

Fig.19 Application rate of 400 kg N / 0 P kg

Fig. 20 Application rate of 400 kg N /50 kg l

Fig. 21 Application rate of 400 kg N / 100 kg P   Fig.22 Application rate of 400 kg N/150 k

4.7 FIELD EXPERIMENT RESULTS

4.7.1 Effect of N and P on the growth and yield parameters of sorghum

The number of tillers per plant, root weight per plant, plant biomass and leaf area as affecte N and P is presented in Table 4. There were no significant differences between numb tillers, root weight, plant biomass and leaf area for all application levels of N fertil However, application of P fertilizer resulted in significant differences in root weight, bion and leaf area but number tillers were not affected by P.

4.7.1.1 Number of tillers

All application rates of N fertilizer did not result in significant difference between number of tillers. However, there was a slight increase in number of tillers as levels of N fertilizer was increased (Table 4). The highest number of tillers was recorded at application rate of 150 kg N ha^{-1} . At 0 kg N ha^{-1} , there were 2.5 tillers per plant and then the number increased to 2.83, 2.66 and 2.88 tillers per plant when N fertilizer level was increased to 50 kg N ha^{-1}, 100 kg N ha^{-1} and 150 kg N ha^{-1} respectively.

The effect of P on the number of tillers per plant is presented in Table 4. There was no significant difference between number of tillers at all application rates of P. Fewer tillers were observed by increasing P rate from 0 to of 12.5 kg P ha^{-1}. Highest number of tillers (3 tillers per plant) were recorded at P rate of 25 kg P ha^{-1} and 37.5 kg P ha^{-1}.

The results presented in Table 6 showed that all combinations of N and P fertilization did not result in any significant difference in number of tillers per plant.

4.7.1.2 Root weight

The results presented in Table 4 showed that there was no significant difference for root weight at all application level of N fertilizers. The highest root weight of 1416.57 kg was recorded at an application rate of 100 kg N ha^{-1} beyond which root weight declined with increasing N application. P application significantly increased root weight per plant (Table 4). The highest root weight of 1503.68 kg was recorded at application rate of 25 kg P ha^{-1} followed by 37.5 kg P ha^{-1}.

Interaction of N and P did not result in significant difference in root weight per plant (Table 6). Highest root weight of 1629.61 kg was produced by combination level of 0 kg N ha^{-1} and 25 kg P ha^{-1}.

4.7.1.3 Biomass per plant

The effect of N and P on biomass of sorghum plant is recorded in Table 4. There was no significant difference in biomass between levels of N fertilizer . However, biomass increased from 2046.27 kg to 2388.86 kg when N Level was raised to 100 kg per ha. P application significantly increased biomass yield. P application at 25 kg P ha^{-1} significantly increased biomass above the control. The interaction of N and P had no effect on biomass yield of sorghum (Table 6).

4.7.1.4 Leaf area

The results of effects of N and P on leaf area is presented in Table 4. N application had no significant effect on leaf area. Even though there was no significant difference, the results showed that highest leaf area of 293.41 cm^2 per leaf was recorded at application rate of 100 kg N ha^{-1}. However, there were differences in leaf area between levels of P and the control. Increasing P level beyond 12.5 kg per ha did not significantly increase leaf area above the control. There was however no interactive effect of N and P on leaf area (Table 5)

Table 4. The effect of nitrogen and phosphorus levels on number of tillers, root weight per plant, plant biomass and leaf area of sorghum plants at in the field

Treatments	Number of tillers	Root weight / ha (Kg)	Plant biomass / ha (Kg)	Leaf area (cm^2)
N level (kg N ha^{-1})				
0	2.50	1357.39	2046.37	282.32
50	2.83	1342.57	2055.53	270.13
100	2.66	1416.57	2388.86	293.41
150	2.88	1222.21	1972.94	261.45
	NS	NS	NS	NS
CV (%)	15.98	23.7	27.3	20.80
SED	0.03	129.26	230.79	23.5
N – Linear	NS	NS	NS	NS
N – Quadratic	NS	NS	NS	NS
P level (Kg P ha^{-1})				
0	2.75	1218.42	2014.05	239.07
12.5	2.50	1231.47	2060.35	310.18
25	2.83	1503.68	2405.53	288.62
37.5	2.75	1385.17	1803.68	269.44
	NS	NS	NS	**
CV (%)	15.98	23.7	27.3	20.80
SED	0.03	129.26	230.79	23.5
P – Linear	NS	**	NS	NS
P – quadratic	NS	NS	**	**

** significant at Prob = 0.05
NS- Not significant at Prob = 0.05

4.7.1.5 Leaf nitrogen

Although the results were not significantly different the leaf N increased with an increase in N level (Table 5). Leaf N increased from 2.40 % at 0 kg N / ha application to 2.88 % at 100 kg N / ha beyond which leaf N decreased. P application increased leaf N in sorghum plants as compared to control but differences were not significant. Highest leaf N (2.72 %) was achieved in application rate of 25 kg P / ha^{-1}.

The results for leaf N were not significant at all combination of N and P fertilizer (Table 7). Combination of 100 kg N ha^{-1} and 12.5 kg P ha^{-1} produced highest protein content of 3.02 %.

4.7.1.6 Leaf phosphorus

There was no significant difference between leaf P for all N levels (Table 5). Application of P fertilizer increased leaf P but differences between application rates were not significant. Leaf phosphorus was not significantly affected by combinations of N and P (Table 7).

4.7.1.7 Seed protein

The effects of N and P fertilizer in protein of sorghum grain is recorded in Table 5. There was no significant difference between grain protein at all levels of N and P fertilizer. However, N and P interaction at 150 kg N ha^{-1} and 25 kg P ha^{-1} increased grain protein by nearly 17 % over the control (Table 7).

4.7.1.8 1000 seeds and head weight

The effects of N and P fertilizer in 1000 seed weight and head weight of sorghum is recorded in Table 5. There was no significant difference between 1000 seed weight and head weight at all levels of N and P fertilizer.

1000 seed weight and head of sorghum were not significantly affected by all combinations of N and P (Table 7). Highest 1000 seed weight of 29 g were recorded at combination of 100 kg N ha^{-1} and 37.5 kg P ha^{-1}. Combination of 100 kg N ha^{-1} and 0 kg P ha^{-1} produced highest head weight of 4340.73 kg.

4.7.1.9 Grain yield

The effect of N fertilizer on grain yield is presented in Table 5. Application of N fertilizer did not significantly affect grain yield of sorghum. The results showed a slight yield increase from 0 kg N ha^{-1} to 50 kg N ha^{-1} beyond which grain yield declined. The effect of P fertilizer on grain yield of sorghum is shown in Table 5. There were no significant differences in yield between P applications. Grain yield was not significantly affected by all combinations of N and P fertilizer (Table 7). However, combination of 50 kg N ha^{-1} and 37.5 kg P ha^{-1} increased grain yield of sorghum.

Table 5. Leaf nitrogen, leaf phosphorus, protein content 1000 seeds weight, head weight, head weight and grain yield of sorghum seeds as affected by nitrogen and phosphorus.

Treatments	Leaf nitrogen (%)	Leaf phosphorus (ppm)	Protein content %	1000 seed weight (g)	Head weight /ha (Kg)	Grain yield (Kg)
N level (Kg N ha^{-1})						
O	2.34	0.09	8.08	26.13	4060.70	2739.71
50	2.44	0.08	8.15	28.28	4184.22	2941.00
100	2.88	0.07	7.63	28.16	4148.85	2863.71
150	2.77	0.14	8.68	26.62	3674.40	2533.53
	**	NS	NS	NS	**	NS
CV (%)	13.44	118.07	14.85	9.37	10.98	16.20
SED	0.14	0.04	0.49	1.05	180.15	183.13
N- Linear	NS	NS	NS	NS	NS	NS
N- Quadratic	NS	NS	NS	NS	NS	NS
P level (Kg P ha^{-1})						
0	2.50	0.06	8.16	26.94	3904.40	2611.12
12.5	2.60	0.11	8.23	27.63	3968.10	2835.82
25	2.72	0.07	8.46	27.37	4052.35	2791.78
37.5	2.60	0.14	7.70	27.46	4143.29	2839.23
	NS	NS	NS	NS	NS	NS
CV (%)	13.44	118.07	14.85	9.37	10.98	16.20
SED	0.14	0.04	0.49	1.05	180.15	183.13
P – Linear	NS	NS	NS	NS	NS	NS
P – Quadratic	NS	NS	NS	NS	NS	NS

** significant at Prob = 0.05

NS- Not significant at prob = 0.05

Table 6. Number of tillers, root weight, plant biomass and leaf area as affected by interaction of nitrogen and phosphorus.

Treatments		Number of tillers per plant	Root weight /ha (Kg)	Plant biomass / ha (kg)	Flag leaf area (cm^2)
N levels(Kg ha^{-1})	P levels (Kg ha^{-1})				
0	0	2.66	1448.13	1851.83	231.26
0	12.5	2.00	1885.17	1851.83	314.61
0	25	2.33	1629.61	2555.53	311.44
0	37.5	3.00	1466.65	1925.91	271.98
50	0	2.66	1333.32	2037.01	247.95
100	0	2.66	1481.13	2481.46	250.57
150	0	3.00	1111.10	1685.91	226.51
50	12.5	3.00	1259.25	2370.35	286.38
50	25	3.00	1496.25	2259.23	304.63
50	37.5	2.66	1481.13	1555.54	241.54
100	12.5	2.33	1333.35	2259.23	337.96
100	25	3.00	1444.43	2814.79	281.29
100	37.5	2.66	1407.39	1999.98	303.78
150	12.5	2.66	1148.14	1759.98	301.77
150	25	3.00	1444.43	1992.57	257.10
150	37.5	2.66	1185.17	1733.32	260.44
		NS	NS	NS	NS
CV (%)		**15.98**	**23.7**	**27.3**	**20.80**
SED		**0.06**	**258.52**	**461.57**	**47**

**** Significant at Prob = 0.05**

Ns – Not significant at Prob = 0.05

Table 7 : Leaf nitrogen, leaf phosphorus, protein content, 1000 seeds weight, head weight and grain yield as affected by interaction of nitrogen and phosphorus levels.

Treatments		Leaf nitrogen (%)	Leaf phosphorus (ppm)	Protein content %	1000 seed weight (g)	Head weight / ha (kg)	Grain Yield (Kg)
N levels($Kg\ ha^{-1}$)	P levels ($Kg\ ha^{-1}$)						
0	0	2.06	0.09	8.05	25.90	3893.29	2441.45
0	12.5	2.41	0.08	7.67	26.80	4088.84	2900.88
0	25	2.48	0.09	8.03	26.76	4100.70	29111.08
0	37.5	2.42	0.10	8.56	25.06	4239.95	2705.60
50	0	2.46	0.06	8.36	27.30	4088.85	2726.19
100	0	2.79	0.05	7.89	28.50	4340.73	2962.78
150	0	2.70	0.06	8.32	26.06	3294.78	2314.04
50	12.5	2.18	0.07	8.61	29.86	4248.84	3049.15
50	25	2.55	0.07	9.04	29.06	4061.44	2878.34
50	37.5	2.55	0.12	6.60	27.70	4337.77	3110.34
100	12.5	3.02	0.08	7.75	27.56	3976.25	2817.75
100	25	2.98	0.08	7.38	27.33	4068.14	2711.08
100	37.5	2.75	0.06	7.50	29.26	4213.29	2963.23
150	12.5	2.80	0.19	8.70	26.30	3638.48	2575.67
150	25	2.85	0.05	9.39	26.30	3982.18	2666.64
150	37.5	2.67	0.26	8.14	27.80	3782.18	2577.75
		NS	NS	NS	NS	NS	NS
Cv (%)		**13.44**	**118.07**	**14.85**	**9.37**	**10.98**	**16.20**
SED		**0.28**	**0.08**	**0.98**	**2.09**	**360.30**	**366.28**

** - Significant at Prob = 0.05
NS – Not significant at Prob = 0.05

CHAPTER FIVE

5.0 DISCUSSION

5.1 Discussion of greenhouse results

Plant height

Application of N fertilizers increased plant height of sorghum. Plants fertilized with application rate of 400 kg ha^{-1} grew taller than plants growing in the control and other treatments. These are in line with Buah and Mwinkara (2009) and Ashion *et al.* (2005) who reported that application of N fertilizer increase plant height of sorghum. Lea and Gaundry (2001) explained that N supply tend to increase the number of meristems produced by sorghum plants and their growth thus encouraging shoot formation and growth.

P fertilizers increased plant height over the control. Highest height was achieved in application rate of 100 kg ha^{-1}. The increase in plant height of sorghum due to application of P fertilizers was also reported by Sumera *et al.* (2002) and Ashiono *et al.* (2005). Tisdale *et al.* (2005) explained that the improvement in growth of sorghum plants under the influence of P could be associated with the ability of P which improves the various metabolic and physiological processes in the plant system. Phosphorus plays a major and important role in the storage of energy and its transfer into the plant system.

Plant biomass

Plant biomass was affected by application of N fertilizer. The highest biomass was recorded at application rate of 100 kg N ha^{-1}. These results are similar to those of Ogunleala (1998) who reported that N fertilization increase total dry matter of sorghum plants. Almodares *et al.* (2009) also found significant increase in biomass due to application of N.

The results show that P increased plant biomass in sorghum plants. Application rate of 100 kg P ha^{-1} produced the highest plant biomass over the control and other application rates. Similarly Akram *et al.* (2007) reported that P fertilizer increase sorghum growth.

Interaction of N and P significantly increased plant height and biomass per plant. These results are similar to those of (Arvin and John 2004) who reported that application of N * P increased biomass and yield of sorghum. Number of leaves per plant, plant nitrogen, protein content and tissue phosphorus were not significantly unaffected by interaction of N and P.

The results of greenhouse shows that sorghum plants respond positively to N and P fertilizers. This good response could be due to good environmental conditions in the greenhouse such as sufficient watering situation which made nutrients readily available for uptake by plants. Murty *et al* (1994) reported that moisture is very important in the response of sorghum to chemical fertilizers.

Number of leaves

N fertilization did not affect the number of leaves in sorghum plants. The between N treatments were similar to those of the control. This results are not in agreement from the findings of Lea and Gaundry (2001), who reported that N increase formation of leaves. However, P fertilization increased number of leaves in sorghum plant over the control. Highest number of leaves (7.04) was recorded at application rate of 150 kg P ha^{-1}.

Plant nitrogen and protein content

Plant nitrogen and protein content was increased by application N fertilizer. Highest nitrogen and protein content was achieved in application rate of 200 kg N ha^{-1}. These results are similar to those of Murty *et al.* (1994), Amed *et al.* (2007) and Almodares *et al.* (2009). These researchers reported that nitrogen fertilizer increase protein content of sorghum. Fertilisation with P did not increase nitrogen and protein content, all application rates of P produced similar plant nitrogen and protein content.

Plant phosphorus content

N fertilization did not increase plant phosphorus content. However, phosphorus content was significantly affected by fertilization with P. Application rate of P produced highest plant phosphorus content.

Pictures of sorghum grown in greenhose

The pictures of sorghum plants showed that all plants grown in combination of N and 0 kg P ha-1 e.g. (0 kg N ha^{-1} and 0 kg P ha^{-1}, 100 kg N ha^{-1} and 0 kg P ha^{-1}, 200 kg N ha^{-1} and 0 kg P ha^{-1}, 400 kg N ha^{-1} and 0 kg P ha^{-1}) were stunted and turned yellowish and purple in colour. During harvesting, after 5 weeks after emergence, it was observed that the plants in these treatments had poor root development. This is because soil used in greenhouse experiment was very deficient in P leading to poor development of root system. Murty *et al.* (1994) explained that deficiency of P result in poor development of roots system leading to poor absorption of nutrients and water from the soil. Poor absorption of water reduced the rate of photosynthesis and this reduced growth of sorghum plants.

5.2 Discussion of field experiment results

Number of tillers

Application of N and P fertilizers did not significantly affect number of tillers. However, a slight increase was observed at the application rate of 150 kg N ha^{-1} and 25 kg P ha^{-1}. These results differ with those of Ogunlela (1988) who reported significant increase in number of tillers due to fertilization with N and P fertilizers.

Root weight

N fertilizers did not affect the root weight of sorghum plants. The results were almost similar between application rates of N and control. It is reported Tisdale *et al.* (2005) that phosphorus plays a major role in root development. It was also observed in this study that P significantly increased root weight. Highest root weight was observed at application rate of 25 kg P ha^{-1}.

Biomass

N fertilization increased plant biomass of sorghum. The highest biomass was observed at application rate of 100 kg N ha^{-1}. This results were not significant and they differ with those of

Ogunlela (1988) who reported significant increase in dry matter production due to N fertilization. Highest biomass was observed at application rate of 25 kg P ha^{-1}. This results are similar to those of Akram *et al.* (2007) who reported that P fertilization increase biomass of sorghum.

Leaf area

In this study N fertilization did not increase leaf area although other researchers such as Ogunlela (1988) reported increase in growth components. However, a significant increase in leaf area was achieved in P fertilization. These results are similar to those of Ogunlela (1988) who reported that P fertilization increase leaf area of sorghum.

Leaf nitrogen, leaf phosphorus, protein content

A similar trend as in the leaf area was observed with the leaf nitrogen, leaf phosphorus and protein content of sorghum plants which were not significantly affected by N fertilization. These results differ with those of Almodares *et al.* (2009) who reported that N fertilization increase protein content of sorghum significantly.

1000 seed weight, head weight and grain yield

The results in 1000 seed weight, head weight and grain yield were not significantly affected by N fertilization. However, there were slight increase at application rate of 50 kg N ha^{-1} These results differ with those of Ashiono *et al.* (2005), Ogunlela (1988) and Sumeria *et al.* (2005) who reported significant increase in 1000 seed weight, head and grain yield due to N fertilization. In this study, 1000 seed weight, head weight and grain yield were not significantly affected by application of P, however, there was a slight increase in grain yield and head weight due to P fertilization. Grain yield increased from 2611 kg at control to 2839 kg when P was increased to 37.5 kg P ha^{-1}. Sumeria *et al.* (2009) reported increase in grain yield due to application of P fertilizer. Improvement in growth of sorghum plants under the influence of P fertilizer could be associated with the ability of P to improve the various metabolic and physiological process in the plant system. Phosphorus plays an important role in the storage of energy and transfer it into the plant system. The energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds (ATP) for use in growth and reproductive process (Tisdale *et al.*, 2005).

CHAPTER SIX

6.0 CONCLUSION

The results of the greenhouse study revealed that N and P fertilizers increased yield components of sorghum plants. The plant height, biomass were significantly affected by application of N and P fertilizers. This indicates that high yield components of sorghum can be increased when application rates of 100 kg N ha^{-1} and 50 kg P ha^{-1} are applied, respectively.

From the results of the field study, it was shown that sorghum can respond positively to both P and N fertilizers. Although the results of most parameters measured were not significant there was a slight increase in number of tillers, root weight, biomass, leaf area, leaf nitrogen, protein content, seed weight and grain yield due to the application of nitrogen and phosphorus fertilizers. Application of P fertilizer resulted in significant difference between root weight, biomass, and leaf area. It was also concluded the high yield and yield components of sorghum can be obtained when application rates of 50 Kg N ha^{-1} and 25 Kg P ha^{-1} are applied respectively.

CHAPTER SEVEN

7.0 RECOMMENDATIONS

1. From the greenhouse study, the results demonstrated an increase in growth parameter therefore there is need to verify these in a field experiment at different locations.

2. The results for grain yield in the field experiment were not significant, therefore the author recommends that, research in the field must be repeated in different soils at different locations in Botswana. This will help researchers to find the correct fertilizer application rates that farmers can use to maximize the yield of sorghum in Botswana.

CHAPTER EIGHT

8.0 REFERENCES

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