Effect of Phosphorus On The Growth, Yield And Nutrient Uptake Of Intercropped Maize (Zea mays (L.) And Cowpea (Vigna unguiculata (L.) Walp)

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

June 2016

BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES

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A dissertation submitted to Department of Crop Science and Production in partial fulfillment of the requirements for the Degree of Masters of Science (MSc) in crop science (Agronomy stream

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STATEMENT OF ORIGNINALITY

I declare that this dissertation handed by me for the qualification of Master of Science degree Agronomy stream at Botswana College of Agriculture/University of Botswana is my independent work and has not been previously submitted by me at another Faculty/ University for the award of any other degree or diploma. I also agree that University of Botswana/Botswana college of Agriculture has the sole right to the publication of the dissertation.

Osenotse Doreen Galetlale

June 2016

DEDICATIONS

I would like to dedicate this dissertation to my heavenly father lord "Jesus". Thank you lord "God" for lifting me up spiritually on this entire work. Secondly I would like to dedicate it to my husband, Mr Kereemang Galetlale, for his encouragement and understanding through the entire period of the write up. Lastly to my children Tshenolo and Neelo who were always supportive too when I was rehearsing for the presentation.

ACKNOWLEDGEMENTS

I would like to thank the following:-

- Prof. Samodimo Ngwako for supervising me during his tight schedule as the Head of Department at Crop science. He advised and corrected me during the write up of the proposal and final thesis. His guidance, patience and corrections yielded direction in this write up.
- Prof. Flora Pule-Meulenberg for sponsoring my project in mineral analysis of cowpea crop seeds. Her sponsorship played major significance in the completion of my dissertation. Prof. Flora Pule- Meulenberg provided guidance with statistical analysis and corrections with the write up too. I would also like to thank her for her encouragement during the write of the thesis and for availing herself when I needed help. Her corrections and patience too have yielded direction to the entire write up of the thesis.
- Botswana University of Agriculture and Natural Resources is also thanked for providing land during the growing of crops as well as the Department of Animal science for allowing me to use their laboratory during digestion of plant materials.
- Department of Agricultural Research Director (DAR) (Plant Material Analysis) for allowing me to work in their Laboratory for soil analysis and plant material analysis. Mr Ngwako and Mr S. Mosweu, The Laboratory technicians at DAR are thanked too for helping with sample analysis using Inductive Coupled Plasma (ICP). The assistance of Mr J. Makore at DAR help is appreciated too for explanations of the experimental design of the research. Lastly, I would like to thank Mr Morekisi at the University of Botswana, Geology Department for assisting with mineral analysis of cowpea seeds using (ICP).

ABSTRACT

In addition to low soil moisture and its holding capacity, constraints to arable agricultural production in Botswana include low levels of nutrients especially phosphorus. The objectives of the study were to determine the effect of phosphorus on the growth, yield and uptake of nutrients by intercropped maize and cowpea. The experiment was conducted at Botswana University of Agriculture and Natural Resources grounds at Sebele, as a split plot in a randomized complete block design with three replications. Four levels of phosphorous as the main treatments were used and the source of phosphorus was single superphosphate. The levels of phosphorus (P) were 0, 50, 100 and 150 kg/ha. There were three sub-treatments being intercropped maize and cowpea, sole maize and sole cowpea. The maize variety was Kalahari Early Pearl (KEP) while a local cowpea landrace Tswana (mogweokgotsheng) were used. Data were tested for normality and subjected to analysis of variance (ANOVA). Application of P did not reveal significant differences on dry matter accumulation. Also, differences in the P application rate did not show significant differences in the uptake of all macro- and micro-nutrients tested in the whole plant dry matter. However, the different cropping systems revealed differences in the uptake of both macro- and micro-nutrients. Intercropped cowpea produced the highest whole plant dry matter in grams compared to sole cowpea, with dry matter for intercropped plants being about 2.3 times more than for sole plants. This could be due to low inter row competition for intercropped cowpea. Thus, maize and cowpea roots explored different parts of the soil due to differences in their root architecture. There was some significant P application rate x cropping systems interactions for Fe and Cu in whole plants as well as Ca, Mg, Na and Fe in cowpea seed. For whole plants, the highest Fe uptake was shown by intercropped cowpea plants that did not receive any P whereas for the seed, intercropped cowpea which received 50 kg P/ha exhibited the highest Fe content. Seed from sole cowpea plants extracted the highest amount of Ca and Mg at all P application levels. Positive, highly significant relationships were established for whole plant P and K (r = 0.7971, p = 0.0000), whole plant P and Mn (r = 0.8577, p = 0.0000), and whole plant P and Fe (r = 0.6160, p = 0.0000) as well as for seed P and Mg (r = 0.7915, p = 0.000004) and seed P and K (r = 0.7949, p = 0.000003). Taken together, this study has shown that application of P did not affect production of dry matter on the Luvisols at Sebele. It has also been shown that P application did not affect accumulation of nutrients in whole plants as well as in the seed. However, it was shown that intercropped cowpea accumulated more nutrients in whole plants and in seed. Therefore, cowpea crop should be should be used in cereal legume cropping system by Batswana farmers because of it ability to accumulate more nutrients.

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CHAPTER 1: INTRODUCTION

1.1 Back ground information

In addition to low soil moisture and its holding capacity, constraints to arable agricultural production in Botswana include low levels of nutrients especially phosphorus (P). Because P is an essential element, its absence in soils means that crops cannot complete their life cycles. Botswana soils are not only low in P, but because of their highly weathered nature, their pH is often low, meaning that they have a tendency of fixing P into insoluble compounds.

Phosphorus is available in the soil solution primarily in the forms of polyprotic phosphoric acid (H_3PO_4). The predominant form of P depends on the pH of the particular soil (Nielsen *et al.*, 2007). Taiz and Zeiger (2010) also put emphasis on the actual concentration of soluble P in most soils as relatively very low, due to several factors. At pH less than 6.8 the predominant form of P is the mono valent orthophosphate anion ($H_2PO^-_4$) (Hopkins 2005; Taiz and Zeiger 2010). In slightly acidic to neutral soils, the predominant form is the HPO_4^{2-} ion. Orthophosphate is readily absorbed by plants roots (Barber, 1985).

Substantial amounts of P may be bound up in organic forms which are not available for uptake by plants. Marschner (1995) reported that organic P may be converted to an in organic form by the action of soil micro-organisms and moreover, plants must also be able to compete with the soil micro-flora for the small amount of phosphorus in the soil. For these reasons P rather than N is the limiting element in natural ecosystems (Pieter *et al.*, 2007).

Between pH 6.8 and 7.2, the predominant form of P is divalent which is less readily absorbed. The optimal soil pH range for P availability is 6-7. In alkaline soils the predominant P is the trivalent form which is virtually unavailable for uptake by the plant (Marschner, 1995). According to Taiz and Zeiger (2010), the actual concentration of soluble

P in most soils is relatively low, due to several factors. At neutral pH , P tend to form insoluble with aluminum (Al) and iron (Fe), while in basic soils calcium (Ca) and magnesium (Mg) will precipitate the P because insoluble phosphates are slowly released into soil solution , P is always limited in calcarious soils (Barber, 1985).

In Botswana, production of maize and cowpea is very low with yields of both crops below a tone per hectare. Chief among factors limiting production is poor soil fertility especially N and P (FAO, 2015). In legume based smallholder production systems, lack of N can be corrected by biological nitrogen fixation while the shortage of P can be ameliorated by the use of inorganic phosphorus fertilizer in these subsistent arable fields.

1.2 Maize production

Worldwide production of maize is estimated at 785 million tons, with largest producer being United States producing 42%, Africa produces 6.5% and the largest African producer is Nigeria with nearly 8 million tons, followed by South Africa (FAO 2015). Africa imports 28% of the required maize from countries outside the continent. Hundred and fifty million hectares of maize are harvested worldwide, and Africa harvests 29 million hectares Nigeria being the largest producer harvesting 3% followed by Tanzania (FAO, 2015).

In Botswana, maize is cultivated by both commercial and traditional farmers under rain fed condition (DAR, 2004). The 2007 and 2008 Agricultural report survey of January 2012 shows that under traditional sector of Botswana, area planted with maize from 1998 to 2008 ranged from 80 000 ha to 120 000 ha respectively, while grain harvested was about 25 000 metric tonnes and 44 000 metric tonnes respectively, which translate to 313 kg/ha and 367 kg/ha both representing low production levels below 100 000 metric tonnes. Therefore, there is the need to add P and intercrop maize with legumes such as cowpeas as there are known for their biological nitrogen fixation.

1.3 Cowpea production

According to FAO (2015), the world production is 3.3 million tons of cowpea from 12.5 million ha. Central and West Africa produce cowpea in about eight million ha, while Central and Central America produce cowpea on an area of about 2.4 million and lastly Asian production is on an area of about 1.3 million ha. As of 2012, the average cowpea yield in Western Africa was estimated as 483 kg/ha which is still 50% below estimated potential production yield. The FAO report shows that in some traditional cropping methods the yield can be as low as 100kg/ ha. In tropical Africa under subsistence agriculture cowpea dry seed yield potential ranges from 100-500 kg ha $^{-1}$ (Vesterager *et al.*, 2007). The Ministry of Agriculture survey report of (2007/2008), indicated that in Botswana, about 30 000 ha are planted to cowpea yearly, with yielding potential of about 600 tonnes of grain (20 kg/ha) and this is way below the potential of 100-500 kg/ha under subsistence agriculture. Hence the there is the need to intercrop cowpea with cereals such as maize fertilized with in organic P to increase the yielding potential of both crops.

1.4 Justification

In Botswana and other arid, semi arid regions; after soil moisture, the most limiting factors in crop production are low natural soil fertility especially P and N, low organic matter and low amount of exchangeable ions (Pule-Meulenberg, 2014). This is a real challenge for resource poor smallholder farmers who cannot afford inorganic fertilizers such as P and N containing fertilizers. Therefore, inclusion of nitrogen fixing legumes such as cowpea can provide the much needed nitrogen fertilizer in maize cowpea intercropping systems, with application of inorganic phosphorus to enhance soil fertility and exchangeable ions.

Different authors recommend different P application rates in sole crops; therefore, there is gap in knowledge on the right amount of P application in intercropping of cereals and legumes hence the need to conduct the study. Furthermore, not much has been done on comparison of different levels of P in legume and cereal intercropping hence the need to conduct the study to compare the intercrop of maize and cowpea with sole crops in relation to levels of phosphorus application.

Botswana farmers are facing problems such as poor soils, semi arid conditions, lack of right agronomic management skills because in a traditional set up most of the farmers do not use chemical fertilizers though they practice some intercropping. The country is still a net importer of cereals (2007/2008 Agricultural survey report of 2012). According to Vesterager, *et al.* (2007), knowledge is lacking on the effects of crop sequences with legumes interchanging with cereals under farmers traditional set up where inorganic fertilizers are rarely used. Therefore, there is need for investigating possible ways in utilizing sparingly soluble phosphorus sources strategically in the cropping sequences in the common maize and cowpea intercrop systems among small holder farmers of Botswana as the country is part of semi-arid Africa. The intercrop with addition of P can be important for the Batswana farmers who can access only small amount of mineral fertilizers for their cereals and legumes such as maize and cowpea. In addition intercropping with legumes such as cowpea may provide some cowpea grain, which has a high value for household food and for sale.

Therefore, there is need for farmers in Botswana to practise agronomic management skills such as, the right intercropping methods with inclusion of legumes and addition of the correct amount of P containing fertilizers to improve yields in subsistence cereal legume crop production. This may also help the country to combat the problem of food insecurity, and the country may be sufficient in food production. According to Snapp et al. (1998), in P deficient soils, grain legume growth can be reduced to a fraction of their potential hence, the need for P application.

Willie (1991) reported low levels of P in Botswana soils. This is especially where the soil has never been cultivated and fertilizer not added. Low levels of phosphorus are also reported in small arable farms where farmers are not used to adding inorganic fertilizers hence the need to add this important mineral. In these small scale farms of Botswana, crops rarely reach their potential yields.

Furthermore, the agricultural sector contribution to the Gross Domestic Product (GDP) has decreased over the years from an impressive 40% at independence (1966) to 2.0% in 2007 and to 1.8% in 2008 (Statistics Botswana, 2012). The report emphasizes the need for rural development to improve agricultural productivity. despite the sectors performance, particularly the arable sector, given the fact that majority of the country's population in the rural areas derive its livelihood from agriculture.

Therefore, the study was conducted to assess the effect of phosphorus on the growth yield, and macro/micro nutrients uptake by maize and cowpea intercropping. The inclusion of inorganic fertilizers such as P in cereal and legume intercrop may be cheaper for arable subsistence farmers especially that Botswana Government nowadays has adopted strategies such as Integrated Support Programme for Arable Agriculture Development (ISPAAD) in which farmers are supplied with free seeds and fertilizers for their arable fields.

1.5 Specific objectives

The objectives of the study were to:

1. Determine the effect of phosphorus on the growth and yield of intercropped maize and cowpea
2. Determine the effect of phosphorus on the uptake of nutrients by intercropped maize and cowpea

1.6 Hypothesis

Hypothesis 1

H0: Addition of phosphorus has no effect on the growth and yield of maize and cowpea intercrop and their sole crops

HA: Addition of phosphorus has effect on the growth and yield of maize and cowpea intercrop and their sole crops.

Hypothesis 2

H0: Addition of phosphorus has no effect on the uptake of macro- and micro-nutrients of intercropped maize and cowpea and their sole crops.

HA: Addition of phosphorus has effect on the uptake of macro- and micro-nutrients of intercropped maize and cowpea and their sole crops.

CHAPTER 2: LITERATURE REVIEW

2.1 Importance of phosphorus in crop production

According to Johnson *et al.* (1996) and Gerke (2000), phosphorus is classified as a major nutrient; meaning that it is required by crops in relatively large amounts even though is frequently deficient for crop production. The total concentration of P in agricultural crops generally varies from 0.1 to 0.5% for most plants which is a very low amount for plant use (Johnson *et al.*, 1996). The deficiency of P in tropical soils was also reported by Agbenin (2005) when he reported that P deficiency was wide spread in savanna soils hence the need for it to be added to these soils during crop production. According to Hopkins (2005), the problem of P in the tropics arises from the numerous reactions it under goes with soil constituents or colloids that render it unavailable for plant use. Quantitatively, its concentration in the soil is between 10-25% of N concentration and only about 5% potassium (K) concentration in soils (Barber 1985). Marschner (1995) states that all plants especially higher plants rely exclusively on macro- and micro-elements for their growth, because they absorb light energy and carbon dioxide to convert them to chemical energy in the form of organic compounds through photosynthesis.

Phosphorus is about the second most important nutrient, next to N, in agriculture; though does not exist in a gaseous form because of the earth's temperature, it plays a significant role in plant and animal nutrition (Nebel and Richard 1998; Taiz and Zeiger 2010). Phosphorus still remains a problem in weathered soils of the tropics hence the need for it to be added to the soils (Marschner, 1995).

The phosphorous cycle begins when phosphates are removed from the rock through weathering and are distributed to the soil and water. Plants will then take phosphate ions from these soils. These phosphates then move from plants to animals when herbivores eat plants and carnivores eat herbivores. They are then absorbed by animal tissues through consumption eventually returns to the soil through excretion of urine and faeces, as well as the final decomposition of plants and animals after death (Elton and Smith, 2002).

2.2 Recommended phosphorus fertilization rates

In Botswana, the recommended rates for P application vary from 200-300 kg/ha of single super phosphate (DAR, 2004). These rates were arrived after field trials based on sole cropped plants. However, because different plants populations are involved in intercropping, there was a need to conduct field trials under intercropped field conditions. Mokwunye, (1977) argued that P fertilization of the soil should be based on phosphate adsorption isotherms in view of the inconsistency of soil phosphorus test as bases for phosphorus fertilization, where such data is lacking such as in the case in Botswana, data from field trials can be used. When using phosphorus adsorption isotherms, Agbenin (1996) concluded that application of between 38 and 40 kg P per ha is adequate to satisfy the phosphorus nutrition of several crops at slightly acid to neutral soils.

2.3 Role of phosphorous in plants

Phosphorus is a constituent of many important macromolecules in plants and animals (Mengel and Kirby, 2001). Such organic compounds like adenosine triphosphate (ATP), ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) contain P, where as ATP is considered to drive biochemical reactions required in living organisms (Marschner, 1995). The RNA and DNA need energy from phosphates which are known to carry genetic inheritance materials and regulate protein synthesis in both plants and animals (Hopkins, 2005).

Phosphorus also plays an active role in photosynthesis, nitrogen fixation, flowering, fruiting and seed formation as well as in crop maturation (Marschner,1995). It also enhances root growth in plants especially lateral and fibrous roots and strengthens structural tissues to prevent lodging in cereals; it improves crop, seed and pasture quality (Mengel and Kirby, 2001). In adequate P availability in plants; leads to stunting, thin and spindly stems, with dark and bluish green foliage (Marschner, 1995; Nielsen and Jensen, 2008). Under severe P stress, plants will be stunted and show purple leaves or foliage (Johnson *et al.*, 1996). Phosphorous is required in large amounts at growing sites of the plants (zone of rapid meristematic activities and it is usually mobilized from older tissues to new tissues where cell division and differentiation are actively taking place (Barber, 1985). When P is lacking, the older leaves or tissues will be the first to show symptoms of P deficiency particularly purpling of leaves followed by senescence or necrosis (Agbenin, 2005). Indicators of P deficiency in plants are delayed maturity, sparse flowering, poor nodule formation by legumes and delayed fruit setting (Johnson *et al.*, 1996).

2.4 Effects of phosphorous in plants

Application of phosphorous at the rate of 100 kg/ha in maize resulted in maximum height of (158 cm), number of cobs per plant (1.25), mass of grains per cob (327 g) and grain yield compared to values in control which had maximum height of (145 cm), number of cobs per plant being (0.80), while mass of grains per cob was (290 g) respectively (Masood *et al.*, 2011).

According to Niamatulla *et al.* (2011), P at two third doses of green fodder maize resulted in maximum number of leaves per m^2 being (40.67) followed by P applied at two doses at sowing time compared to control where number of leaves were minimal. They observed the minimum number of leaves in control plants was 34.67 and that when P was given at half dose it was higher at 36.33. They concluded that P given at two third at sowing and one third at knee length had yielded the best in green fodder maize. In another study by Hajabasi and Schumacher (1994) during the vegetative growth stages (V1-V6) of two varieties of maize CM 37 and W153 R, addition of P was found to have increased the relative growth rate of shoot to a greater degree in CM 37 than in W153R.

Rashid and Iqbal (2012) found out that the maximum fodder yield of maize (42.35) and (42.35) Mg/ ha was obtained where P was applied at the rate of 53 and 55 kg/ha respectively while the minimum was from control plots which was 11.24 Mg /ha. Research by Sigh *et al.* (2011) also showed that irrespective of varieties of cowpea, application of P at the rate of 60 kg/ha had resulted in higher yields of cowpea (1 .4 tons/ha relative to 0 kg/ha that yielded 1.0 ton/ha).

Results on the application of 30 kg/ha of Triple Super Phosphate(TSP) which contains P showed highest grain yield of cowpea where the highest grain yield was 434 kg/ha and lowest was 127 kg/ha in control (Odundo *et al.*, 2009). In that study, there were significant DM responses to super phosphate application. In another study by Ndor *et al.*, (2012) application of 40-kg of P/ha gave higher nodulation per cowpea plant and seed yield per plant. Seed yield average was 1.53 tons/ha where P was applied compared to control which was 1.0 ton/ha.

The study carried out by Islam *et al.* (2001) indicated that cowpea which were inoculated with mychorrizal fungi and fertilized with rock phosphate at the rate of 30 kg/ha responded positively with increased yield in both pot experiments and in the field. Their results also indicated that inoculated plants supplied with rock phosphate flowered earlier and took more P than plants without rock phosphate (RP) inoculation. Phosphorous was also reported to be having a positive relationship with Zn (Orabi and Abdel-Aziz, 1982). These authors in their studies reported that the application of P increased the uptake of Zinc (Zn) as well as the Zn content in the maize plant.

Although many studies have been conducted on the effect of P and growth development of maize and cowpea, such as by Mugwira and Hague (1991), Rashid and Igbal (2011) and many others, those were done on sole crops. Therefore, more studies on maize cowpea intercrop are needed. Snapp *et al.* (1988) suggested that targeted use of 30 kg P/ha on legume maize intercrop can consistently increase productivity of both legume and maize by 100% under small scale farm conditions. Such studies should be undertaken for different legumes, since crops differ in their nutrient uptake. In addition, maize varieties will vary in the way they up take nutrients and assimilate them. Hence, the need to investigate the effect of phosphorus fertilizer on maize and cowpea intercrop under conditions prevailing at Sebele.

Studies conducted by Nour *et al.* (2000) on the effect of N and P on the growth and yield of maize showed that grain yield of maize increased with addition of N while the crop showed a poor response to P application as no increase in yield was obtained with addition of phosphorus up to 86 kg/ha. Therefore, due to all these contradictory research results on the effect if P on growth of maize and cowpea, there is need to conduct a study to ascertain the levels of phosphorus required for maize and cowpea under intercropping.

2.5 Effects of intercropping in crop production

Ouma and Jeruto (2010) define intercropping as a system of growing two diverse species of crops on a piece of land at the same time with the assumption that they improve the efficiency of using both above ground and below ground resources compared to growing them separately. Intercropping is a simultaneous cultivation of more than one crop species on the same piece of land and is regarded as the practical application of basic ecological principles such as diversity, competition and facilitation (Nielsen *et al.*, 2007). Owuor *et al.*, (2002) emphasized that the total productivity of intercropping is more than growing any component crop alone.

Positive effects of intercropping include increased production (Maasdorp and Titterton 1997), improved soil fertility (Rukazamba *et al.*, 2001) and reduced incidences of pests and diseases (Bekunda and Woomer, 1996). Maasdorp and Titterton (1997) showed that the yield of maize intercropped with lablab in Zimbabwe doubled to 1300 kg/ha. Snapp *et al.* (1998) also conducted a study on grain legume in small holding farms in Zimbabwe and Malawi and they concluded that groundnuts in small holder farming system can contribute to net annual amount from negative to around 70 kg N per hectare. They also concluded that intensification of combined use of small inorganic fertilizers especially P in legumes provided some grain yield with high leaf quality residues which offered enhanced nutrient efficiency with improved food security. They stated that in P deficient soils grain legume growth could be reduced to a fraction of their potential. Their study indicated that targeted use of 30 kg/ha of P on maize legume intercrops can consistently increase productivity of both legume and cereal up to 100% under small holder farm conditions.

According to Rukazamba *et al.* (2001) one important reason for intercropping is the improvement and maintenance of soil fertility. Rukazamba *et al.* (2001) gave an example of a cereal crop or tuber crop being intercropped with legumes (beans, peas and groundnuts). After the intercrop is harvested, decaying roots and fallen leaves provide nitrogen and other nutrients for next crop. However, recent studies have shown that up 10% of the fixed N can leak from the legume and immediately benefit a non-leguminous crop. The crop residues of legumes can also be used as fodder by cutting or carrying it to the animals or by letting the animals graze residues in the field (Yilmaz *et al.*, 2007). The nutrients in the crop residues can also be recycled while manure from these animals can be used to fertilize the crops. Legumes in an intercrop system also provide nutrients in the soil, due to decaying crop remains resulting in improved structure, reducing need for soil tillage (Sakala *et al.*, 2000). Water losses, soil erosion and leaching of nutrients are also reduced in intercropping systems due to improved structure and better soil cover. They stated that if fertilizers are applied, it is necessary to use nitrogen fertilizers on the cereal crop. Fertilizers are more efficiently used in an intercropping system, due to increased amount of humus and the different rooting systems of crops as well as differences in the amount of nutrients taken up (Rukazamba *et al.*, 2001; Sakala *et al.*, 2000).

Bekunda and Woomer (1996) reported that there is reduction of insect pest population in intercropping due to the diversity of crops grown and reduction of plant pests and diseases ecause the distance between plants of the same species is increased due to inter planting of rops. Then, there is alteration of more beneficial insects especially when flowering crops are ncluded in the cropping system, increase in farm production and profitability and reduction f weed population through allelopathy and efficient crop production (Ouma *et al.*, 2010). This is also supported by Yilmaz *et al.* (2007) in a study on intercropping maize with cowpea and growing them as sole crops. Their results showed definite yield increase and economic advantage in intercropping compared to sole cropping. In their study intercropping showed high monetary advantage index (MAI) compared to sole cropping. Furthermore, while the intercrop provides a good soil cover, soil temperature will also stay relatively low; this prevents burning of organic matter in the soil and loss of nutrients, it also provides micro climate that can be favorable for associated crops (Yilmaz *et al.*, 2007).

Though intercropping has more advantages compared to sole cropping, it has potential problems. Depending on the crops intercropped, competition for water, light and nutrients may results in lower yields (Reddy and Willey 1981; Roger and Dennis 1993). Changing in spatial arrangement of the crops will reduce competition (George and Jeruto, 2010). A larger distance between the plants reduces competition for water. Other problems in intercropping systems are difficulties in mechanization and increased labour requirements (Roger and Dennis, 1993).

There has been an increase in growers interest in using intercropping since it could reduce management inputs that result in sustainable systems more efficiently using an even potentially replenishing natural resources used in crop management of farmland (Ouma and Jeruto, 2010). Recent, research by Khan *et al.* (2002) and Vesterager *et al.* (2007) has shown that legume roots, rhizome deposits and residues are important nitrogen pools which may also improve soil physical properties and yield of the cereal crop following legume rotation. Advantages of intercropping include risk minimization, effective use of available resources, and efficient use of labor, increased crop productivity, erosion control and improved food security (Bekunda, and Woomer, 1996; Owuor *et al.*, 2002).

In a study by Nielsen and Jensen (2008) where cowpea and maize were grown as intercrops and sole crops, it was shown that the amount of N_2 fixed was 30-40% higher when P was applied in intercropped maize whereas cowpea yield were not affected. The intercropped maize with a population of 19,000 plants/ ha accumulated the same amount of N as 38,000 sole cropped maize though intercropping reduced the dry matter accumulation by 25%. They found out that up take efficiency of the applied P fertilizer was 26%. The study carried by Long *et al.* (2007) where maize, faba bean (*vicia faba* L.) and wheat were intercropped also indicated that intercropping maize with faba bean improved maize grain yield and above ground mass marginally significantly, when compared with maize grown with wheat. In their study they concluded that maize over yielding resulted from its uptake of P which was mobilized by acidification of the rhizosphere via faba bean root release of organic acid and protons. Faba bean over yielded because its growth season and rooting depth was different from of maize. They concluded that under N deficient conditions, P application did not increase the yield of maize. However, their study had limitations because it did not indicate application rate of phosphorous and the form of P applied.

Pieter *et al.* (2007) in their research on maize legume rotation also found out that application of rock phosphate increased yields and P uptake of both maize and velvet bean and maize following maize. They again concluded that the incorporation of legumes in maize based cropping systems, compared with phosphate rock application increased the yields of subsequent maize crop compared to maize mono-cropping system with phosphate rock application, achieving 72% of the maximal yield observed in the reference treatment with triple super phosphate application to maize. In their results it showed that on average 160 g rains per maize plant equivalent to 8.5 tons /ha, was achieved where 90 kg rock phosphate vas applied per hectare.

n conclusion, this review has shown that although many studies have been conducted on the ffect of P on growth and development of maize and cowpea, very few were specifically done n the intercropped maize and cowpea in Botswana.

CHAPTER 3: MATERIALS AND METHODS

3.1 The study-area and site description

The experiment was conducted at Botswana University of Agriculture Farm situated at latitude of 24° 33' S and longitude of 25° 57'E at an altitude of 994 m in Sebele. The average annual rainfall (30 year mean) is about 538 mm and monthly minimum and maximum temperatures are 12.8° C and 26.6° C respectively. Sebele soils on which the experiment was carried out are classified as Luvisols with the coarse and medium sand pre-dominating the top horizon. The silt content is very low throughout the profile ranging from 2 and 3% only (Willie, 1991). Prior to the experiment, the soil was sampled and analysed for some chemical properties. Table 3.1 shows some chemical characteristics of the soil prior to the experiment.

Table 3.1: Some chemical properties of experimental site soil at Sebele

Parameter measured	Measured soil content	Optimum level
pH($CaCl_2$)	4.92	<6.00
OC (%)	0.24	>0.20
CEC (Cmol/kg)	1.82	>2.50
Phosphorus (mg/kg)	6.15	<10.00
Calcium (Cmol/kg)	0.40	>1.00
Magnesium (Cmol/kg)	0.13	>0.30
Potassium (Cmol/kg)	0.15	>0.15
Sodium (C mol/kg)	0.03	<1.00

CEC= Cation Exchange Capacity, OC = Organic Carbon

3.2 Experimental procedure and design

The experiment was a split plot in a complete randomized block design with three replications. Four levels of P as the main treatments were used and the source of P was single superphosphate. The levels of P were 0, 50, 100 and 150 kg/ha. There were three sub treatments namely intercropped maize and cowpea, sole maize and sole cowpea. The maize variety was Kalahari Early Pearl (KEP) while a local cowpea landrace Tswana (mogweokgotsheng) were used.

Thirty six plots each measuring 3 x 2 m in an area of 432 m^2 were prepared to a fine tilth in preparation for planting. Four levels of P fertilizer (0, 50, 100, 150 kg P/ha) were applied as basal dressing in treatment plots after randomization two weeks before planting. The basis for selecting was that different authors in literature recommend different application rates. P was applied by evenly broadcasting in each treatment plot. This was done to allow phosphate fertilizer to mix with the soil in preparation for crop growth. The inter-row spacing of 45 cm and intra-row of 30 cm was used when planting the crops which lead to a population of 1008 plants in an area of 432 m^2 which is equivalent to 74,000 plants per hectare. The maize and cowpea inter crops were planted in alternating rows. Other agronomic practices such as weeding; watering to field capacity, as well as pest control was carried out after planting, whenever necessary. The variables measured per replication in each treatment included the dry Stover weight, seed yield and micro- nutrient such as Mn, Fe, Cu, Zn and Mo and macro-nutrient such as N, P, K, Ca, Mg, and Na contents in shoots. However, the measurement for N seeds was not done as the instrument used for other nutrients could not analyze N. Most samples which were used to analyze other nutrients were missing hence Lack of N seeds.

3.3 Data collection and analysis

Three plants were randomly selected from each plot within the inner rows in each replication at the end of the experiment; their seeds were threshed and weighed using an electronic scale. The mass for each plant was determined by weighing the seeds for that plant and the mass for all the three plants added together to find the total mass for each level of P. The total mass was then divided by the number of plants. This was done to find the average mass of one plant for each P level. Then the seed yield was converted to kg/ha.

The oven dried plant material (plants Stover and seed) were ground and digested with concentrated sulphiric acid according to Page *et al.* (1982). The seeds were ground separately from Stover. Total nitrogen in Stover was determined using the Kjeldahl Nitrogen-(TKN) procedure. The concentration of P, Na, K, Mg, Ca, Fe, Zn, Mo, Cu, and Mn were determined following procedures as outlined in AOAC (2012) using inductively coupled plasma (ICP).

3.4 Statistical Analysis

The Data collected on whole plant dry matter, seed dry weight, as well as N, P, Na, Mg, Ca, and Mn, Fe, Cu, Zn, and Mo contents in Stover and seed were subjected to normality before a two way analyses of variance (ANOVA) was carried out. Where significant interaction was found, an interaction graph was constructed. Correlation analyses were used to determine the relationship between P application rates and nutrients concentration in Stover and seeds. The treatment means were separated and compared using the Duncan's multiple range Test (DMRT) at 5% probability levels where P application rate and cropping systems were tested. All these tests were carried out using STATISTICA 2010 package (StaSoft Inco., Tulsa, OK, USA). Treatment means were separated and compared using the Duncan's multiple range Test (DMRT) at 5% probability levels where P application rate and cropping systems were tested.

CHAPTER 4: RESULTS

4.1 Effect of P on macro nutrient uptake in stover

The analysis of the results using a two Way Analysis of Variance (ANOVA) revealed no significance differences in the effect of P on dry matter accumulation (Table 4.1). The P application rate also did not show significant differences in the uptake of all macro-nutrients tested (N, P, K, Na, Mg and Ca) in the whole plant dry matter. This may be attributed to the soil of poor agricultural quality from OM and low pH (Table 3.1). Significant $p \leq 0.01$ differences were, however, observed for dry matter accumulation in all cropping systems as showed by the higher intercropped maize biomass compared to sole maize, and higher intercropped cowpea compared to sole cowpea. The P application rate x cropping system interaction was not statistically significant (Table 4.1).

There was variation in the uptake of macro-nutrients among the different cropping systems. For example, N uptake was highest ($p \leq 0.001$) in sole and intercropped cowpea and lowest ($p \leq 0.001$) in maize crops while P uptake was highest ($p \leq 0.001$) in sole cowpea, intercropped cowpea and sole maize and lowest in intercropped maize (Table 4.1). Interestingly, K uptake was somewhat similar to that of N with sole and intercropped cowpea plants showing the highest accumulation of K ($p \leq 0.01$) followed by sole maize crop; with intercropped maize showing the least amount of K. Sodium in whole plants material was highest in sole maize plants (624.5±38.6a), while sole cowpea, intercropped cowpea and intercropped maize had almost similar contents. Contents of Mg and Ca followed the same trend as N and K, where sole cowpea and intercropped cowpea showed the highest whole plant material content. For all macro-nutrients with respect to uptake by whole plants materials, there was no significant interaction between P application rates x cropping system (Table 4.1). All macro-nutrient values are very low irrespective of P treatment due to poor soil nutrient status during the study.

Table 4.1: Effect of P on macro-nutrient concentration in monocropped maize and cowpea, intercropped maize/ cowpea stover plants. The treatment means were computed by grouping means of sole maize/ cowpea, intercropped maize/ cowpea whole plant dry weight. Means ±SE with different letters in the same column are significant at P ≤ 0.01(**) and P ≤0.001 (***).

Treatment	Whole plant stover dry weight (g)	N	P	K	Na	Mg	Ca
		(mg/kg)					
P application rate (kg/ha)							
0	86.1±18.7	2877.6±351.5	1150.8±151.9	10289.8±1321.9	500.9±26.6	1566.2±169.1	3251.7±455.9
50	78.8±11.7	3022.7±354.2	1172.6±179.9	10947.2±1412.8	505.8±41.8	1641.4±181.3	3177.0±481.2
100	124. ±36.2	3064.8±401.4	1029.8±154.7	10379.5±1417.5	451.7±35.9	1629.1±185.0	3689.5±598.4
150	110.5±29.1	2854.0±467.3	1125.2±175.7	9666.1±1299.7	467.0±40.1	1670.7±193.8	3388.0±531.9
Cropping system							
Sole maize	39.0±6.0c	1509.8±185.2b	1113.7±115.2a	8256.8±933.1bc	624.5±38.6a	969.0±86.7b	678.6±43.2b
Sole cowpea	94.3±8.7b	4597.1±252.4a	1543.6±189.9a	13483.6±1628.9a	470.5±16.5b	2473.4±132.5a	6157.2±267.1a
Intercropped maize	47.0±4.2b	1378.1±178.2b	349.4±53.1b	6995.5±1138.0c	404.7±50.5b	732.0±133.2b	312.6±70.4b
Intercropped cowpea	219.9±44.2a	4334.1±487.4a	1471.5±181.1b	12546.7±1334.8ab	425.6±16.2b	2333.1±143.8a	6358.0±235.6a
2 Way ANOVA F-Statistics							
P application rate	0.8455ns	0.1172ns	0.1807ns	0.1556ns	0.6076ns	0.1156ns	1.625ns
Cropping system	12.97510***	32.7530***	13.63999***	5.7076**	8.6944***	48.6842***	352.473***
P app rate x cropping system	0.55969ns	1.0395ns	0.7902ns	0.2437ns	1.2492ns	0.4626ns	1.751ns
CV	140.22	63.67	81.74	79.67	42.38	49.09	30.05

4.2 Effect of p on micro-nutrient uptake in Stover plants

Table 4.2 shows the effect of P application on micro-nutrient uptake of sole cowpea/maize plants as well as intercropped maize/cowpea. The application of P had shown no significant effect on the uptake of all micronutrients (Mn, Fe, Cu, Zn, and Mo) just like in the uptake of macro-nutrients in this study. However, there were significant variations in the micro-nutrient uptake for the different cropping systems (Table 4.2). For instance, sole and intercropped cowpea exhibited the highest Mn (333.4±46.1a) and (470.1±63.6a) and Mo (6084.3±213.0a) and (6117.5±a255.9a) contents respectively while sole and intercropped maize showed the least values (2884.2±565.4b) and (3336.9±499.1b). With respect to Fe and Zn, sole plants of maize and cowpea contained the highest amounts (78.5±3.7a) and (51.5±2.0b) compared to intercropped counterparts plants. The trend for Cu uptake for the various crops was different from that of other micronutrients, in this case, intercropped cowpea revealed the highest uptake of Cu (7.6±1.2a), and followed by sole maize (.2±1.3ab) while sole cowpea and intercropped maize showed the least amounts (3.7±0.9bc) and (1.5±0.3c) respectively. Intercropped maize showed the lowest values in Mn, Fe, Cu, and Zn uptake. In addition, statistical significant interactions of P application x cropping system were found for Fe and Cu (Table 4.2).

Table 4.2: Effect of P on micro nutrients uptake by mono cropped maize/cowpea, intercropped maize/cowpea stover plants. The treatment means were computed by grouping means of sole maize; sole cowpea intercropped maize and intercropped cowpea whole plants.

Treatment	Mn	Fe	Cu	Zn	Mo
P application rate (kg/ha)				(mg/kg)	
0	259.2±44.9	418.5±68.5	5.1±1.2	55.7±3.8	4631.5±509.3
50	196.0±35.0	386.4±69.0	3.2±0.5	58.1±3.9	4708.4±415.2
100	277.0±53.2	389.1±74.6	5.1±1.3	56.2±5.1	4342.±3472.1
150	274.8±58.7	501.4±116.9	5.6±1.1	57.8±4.0	4740.7±529.7
Cropping system					
Sole maize	154.0±19.9 b	749.2±124.1a	6.2±1.3ab	78.5±3.7 a	2884.2±565.4 b
Sole cowpea	333.4±46.1a	480.3±71.9b	3.7±0.9bc	51.5±2.0 b	6084.3±213.0 a
Intercropped maize	49.5±9.1b	156.5±28.7c	1.5±0.3c	47.5±5.6 b	3336.9±499.1 b
Intercropped cowpea	470.1±63.6a	309.5±44.9bc	7.6±1.2a	50.4±2.3 b	6117.5±255.9 a
2 Way ANOVA Statistics					
P application rate	0.8685ns	0.5289ns	1.10512ns	0.1017ns	0.1837ns
Cropping system	21.0243***	11.8388***	7.38930**	15.6097***	16.8166***
P application rate x cropping system	1.0512ns	2.2973*	1.97250*	1.5439ns	0.4587ns
CV	99.80	106.24	122.65	39.21	55.65

Means ± SE with different letters in the same columns are significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**) and $P \leq 0.001$ (***)

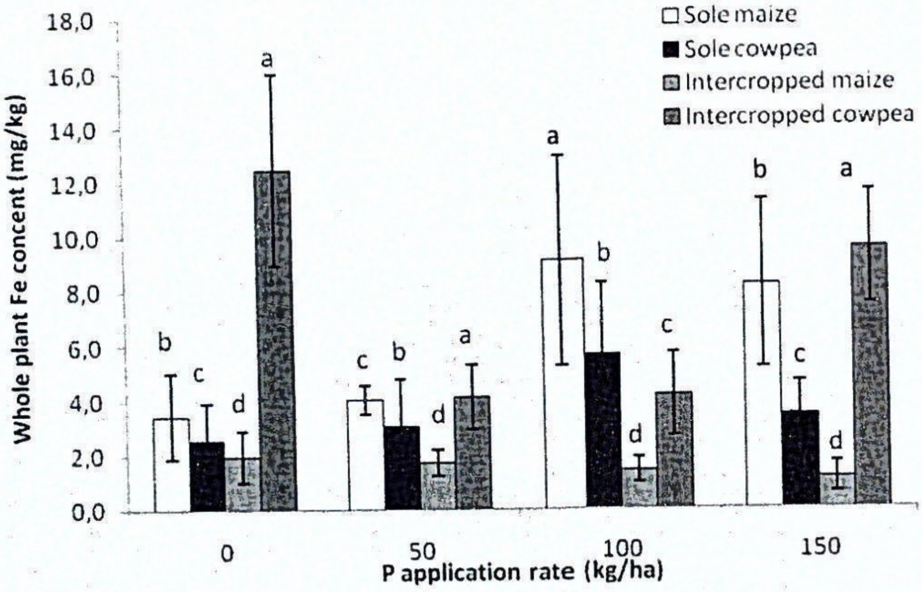

Figure 4.1: Interactive effect of phosphorous on uptake of Fe on monocropped maize/cowpea and their intercropped whole plants.

Figure 4.1 showed that for the 0 and 150 kg P/ha, intercropped cowpea exhibited the highest uptake of Fe, in each case followed by sole maize and sole cowpea then followed by intercropped maize respectively. For the 100 kg P/ha application, sole maize plant extracted more Fe from the soil, followed by sole cowpea, then intercropped cowpea and intercropped maize respectively.

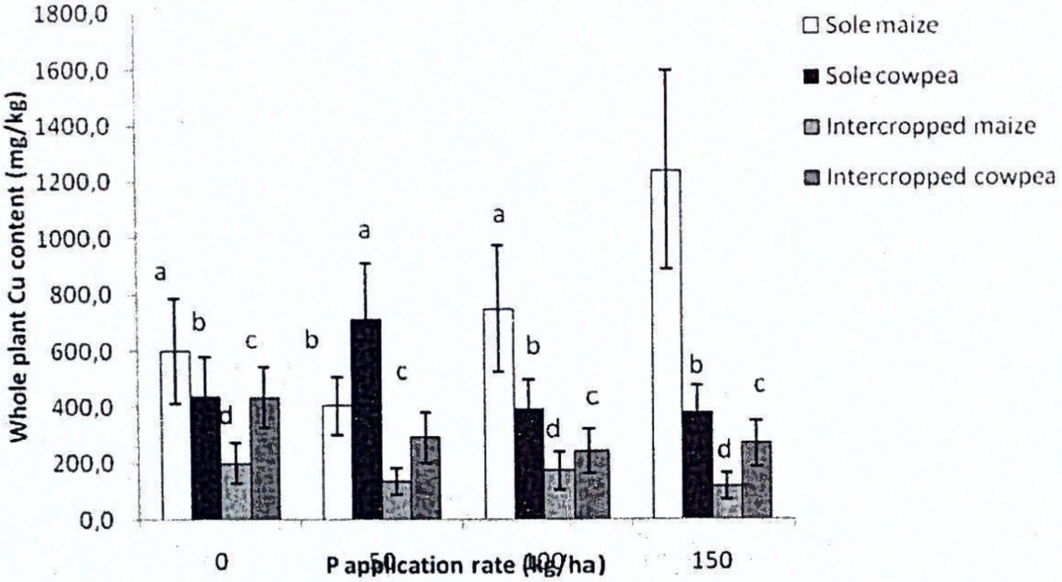

Figure 4. 2: Interactive effect of Phosphorous on uptake of Cu by monocropped maize/cowpea and their intercropped whole plants.

The P application rate x cropping system revealed that for 0, 100 and 150 kg P/ha, sole maize plants extracted the most Cu, followed by sole cowpea then intercropped cowpea while the least was intercropped maize (Figure 4.2). For the 50 kg P/ha application rate, sole cowpea plants had the highest Cu uptake followed by sole maize plants then intercropped cowpea while intercropped maize still showed the least amount.

4.3Effect of phosphorous on macro- and micro-nutrient in cowpea seeds

Seeds harvested from 150 kg P/ha plots revealed the highest P content (115.5±8.3a), while seeds from 0 plots showed the lowest values (88.0±9.8c). There were no differences in seed K, Ca and Na contents among the P treatments. Interestingly, Mg was the only element whose uptake was significantly ($p \leq 0.05$) different for the P application rates (Table 4.3). The 100 kg P/ha rates exhibited the highest Mg uptake, while seeds from the control plots cowpea seeds showed the least Mg uptake (64.4±2.4b). With respect to cropping systems, seeds from mono-cropped plants extracted more P, K, Ca and Mg from the soil compared to those from the intercropped ones. There were no significant ($p \leq 0.05$) differences in the Na content of cowpea seeds between mono-cropped and the intercropped seeds (Table 4.3).

Table 4.3: Effect of P on macro nutrients uptake by mono cropped and intercropped cowpea seeds. The treatment means were computed by grouping means of mono cropped and inter cropped seeds.

Treatment	P	K	Ca	Mg	Na
P application rate (kg/ha)		(mg/kg)			
0	88.0±9.8c	114.0±5.4b	14.1±0.5a	64.4±2.4b	5.0±0.8a
50	92.8±9.9bc	118.6±4.7ab	14.8±1.1a	65.5±2.7ab	5.1±0.8a
100	104.2±8.0ab	116.8±6.4ab	14.1±0.7a	68.6±1.1a	4.3±1.0ab
150	115.5±8.3a	127.4±7.4a	13.7±0.4a	67.9±1.1ab	3.5±1.1b
Cropping system					
Monocropped cowpea seed	118.7±3.6a	128.3±4.4a	15.4±4.4a	70.1±0.6a	4.7±0.6a
Intercropped cowpea seed	81.6±4.3b	110.1±2.0b	13.0±2.0b	63.1±1.3b	4.2±0.6a
2-Way ANOVA F-Statistics					
P app rate	10.870***	1.536ns	0.971ns	3.74*	1.1480ns
Cropping system	99.204***	15.025**	28.936***	44.76***	0.56ns
P app rate x cropping system	0.674ns	0.844ns	4.016*	4.26*	6.5133**
CV	4.92	8.03	6.51	3.37	38.97

Means ± SE with different letters in the same column are significant at P≤ 0.05 (*);P≤ 0.01 (**) and P≤ 0.001 (***)

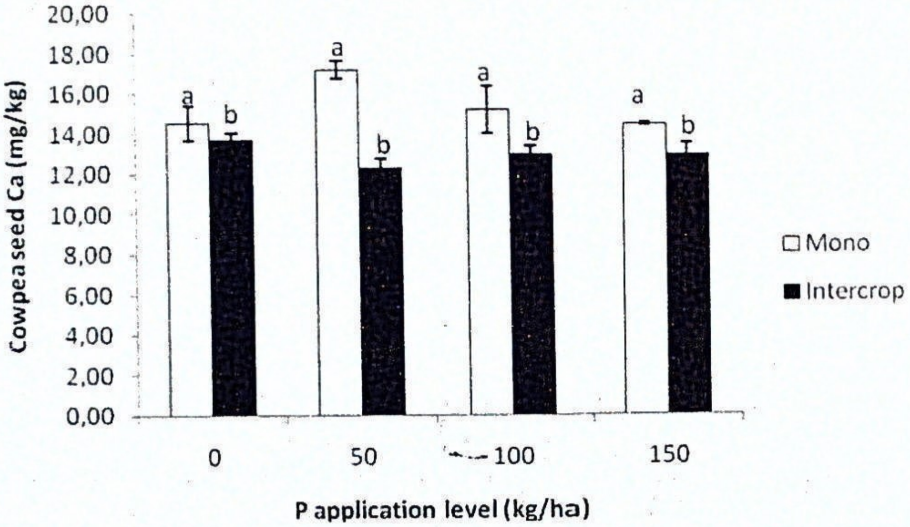

Figure 4.3: Interactive effect of phosphorous on Ca uptake by monocropped and intercropped cowpea seeds.

There were significant P treatment x cropping systems interaction for seed content of Ca, Mg and Na (Figures 4.3- 4.5). For all P treatments, cowpea seeds from monocropped plants showed a significantly ($p \leq 0.005$) higher Ca and Mg content. In the case of Ca, the 50 kg P/ha treatment showed numerically the highest value of 18 mg/kg compared to seeds from the intercropped plants (Figure 4.3). The concentration of Ca in seeds from mono-cropped plants ranges between 14.00 and 18.00 mg Ca/kg while seeds from intercropped plants range between 12.00 and 14. 00 mg/kg. Seed Mg content of mono-cropped was about 70 mg/kg for all P treatments whereas it ranged between 60.00 mg/kg in the case of intercropped plants.

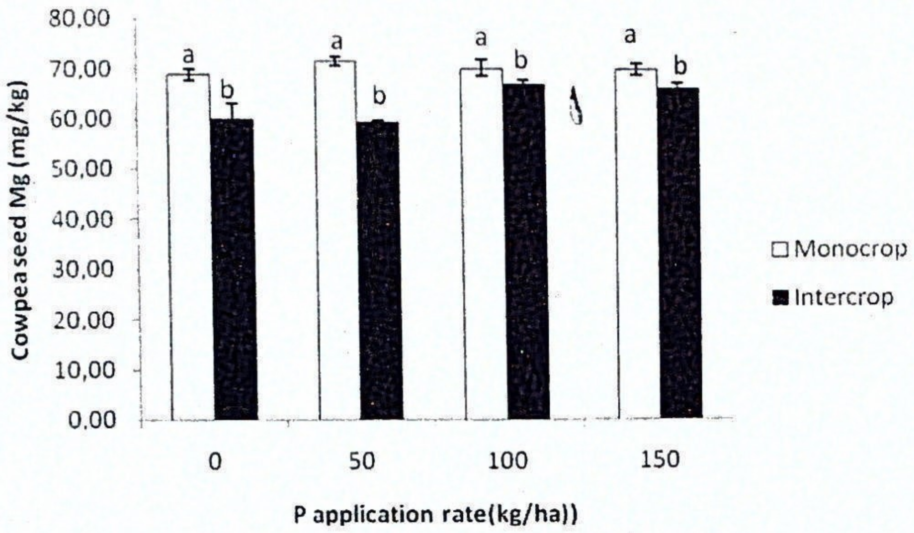

Figure 4.4: Interactive effect of phosphorous on Mg uptake by monocropped and intercropped cowpea seeds.

The interactive effect of P application on seed Na content is shown in Figure 4.5. The 0 and 100 kg P/ha rates showed higher seed Na content (5.1±0.8a) and (5.0±0.8a) for the intercropped cowpea seeds compared to the mono-cropped seeds. The 50 and 150 kg/ha rates had the opposite trend where the Na content was significantly and statistically different and higher in mono-cropped seeds than inter cropped ones.

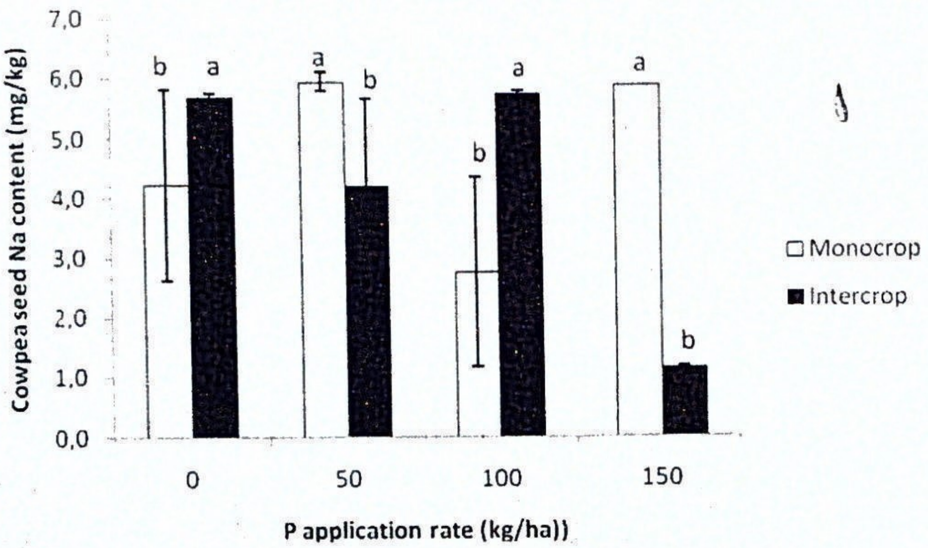

Figure 4.5: Interactive effect of phosphorous on Na uptake by monocropped and intercropped cowpea seeds

Table 4.4 Effect of P on seed weight and micro nutrients uptake by mono cropped/intercropped cowpea seeds. The treatment means were computed by grouping means of mono cropped/intercropped seeds.

Treatment	Seed weight (g/plant)	Mn	Fe	Cu	Zn	Mo
P Application Rate(kg/ha)				(mg/kg)		
0	28.38±5.09	1.1±0.3	0.3±0.2	8.5±2.1	0.14±0.08	0.2±0.1
50	34.03±3.00	0.9±0.1	0.2±0.0	12.5±4.0	0.05±0.03	0.1±0.0
100	34.87±4.70	0.9±0.1	0.2±0.0	9.6±3.5	0.02±0.01	0.0±0.0
150	52.28±9.17	0.8±0.0	0.1±0.0	5.9±1.5	0.06±0.0	0.1±0.0
Cropping system						
Sole Cowpea	33.13±3.56	0.9±0.1a	0.1±0.0	5.5±5.5a	0.03±0.03	0.03±0.0
intercropped cowpea	41.66±5.54	1.0±0.2a	0.3±0.1	12.8±2.2b	0.11±0.04	0.1±0.0
2Way ANOVA Statistics						
P application rate	2.8589ns	0.6520ns	0.77084ns	2.5257ns	1.241048ns	1.522364ns
Cropping system	1.983ns	0.5706ns	1.56701ns	18.6030***	2.344193ns	1.170596ns
P Application Rate x Cropping system	0.3187ns	0.9187ns	0.56496ns	8.6187**	0.810400ns	0.521510ns
CV		51.19	52.31	124.29	191.28	135.64

Means ± SE with different letters in the same column are significant at $P \leq 0.01$ (**) and $P \leq 0.001$(***)

No data is being reported for the maize seed yield due to disturbance of the trial by livestock. For cowpea, there are no significant ($p > 0.05$) differences in yield as a result of variation in P levels. Application of P had no significant ($p>0.05$ effect on the accumulation of micro-nutrient (Mn, Fe, Cu, and Mo) on cowpea seeds (Table 4.4). There were also no Significant ($p> 0.05$) differences between seeds of mono-cropped and intercropped plants with respect to micro-nutrients content except for Cu which was higher in seeds from intercropped plants compared to mono-cropped ones. Furthermore, it is noteworthy that a significant P application x cropping systems interaction was only found for Cu.

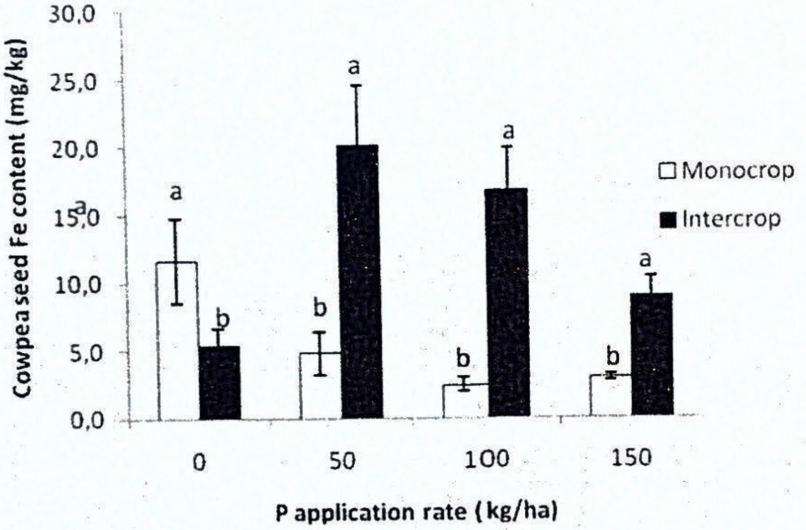

Figure 4.6: Interactive effect of phosphorous on Fe uptake by monocropped and intercropped cowpea seeds.

4.4 Correlation relationship between phosphorus application and nutrients uptake by plants Stover and cowpea seeds.

A correlation analysis was done using measured concentration of macro and micro-nutrients in plants Stover. The data showed that there was a significant positive correlation between P amount and other macro- nutrients in both whole plants and cowpea seeds. When P was subjected to correlation with other nutrients the data revealed a significant positive correlation between plant Stover P content and plant Stover K content (r = 0.7971: p = 0.0000) (Figure 4.7). The relationship shows that increased amount of P in whole plants material resulted in increased accumulation of K in plant Stover material.

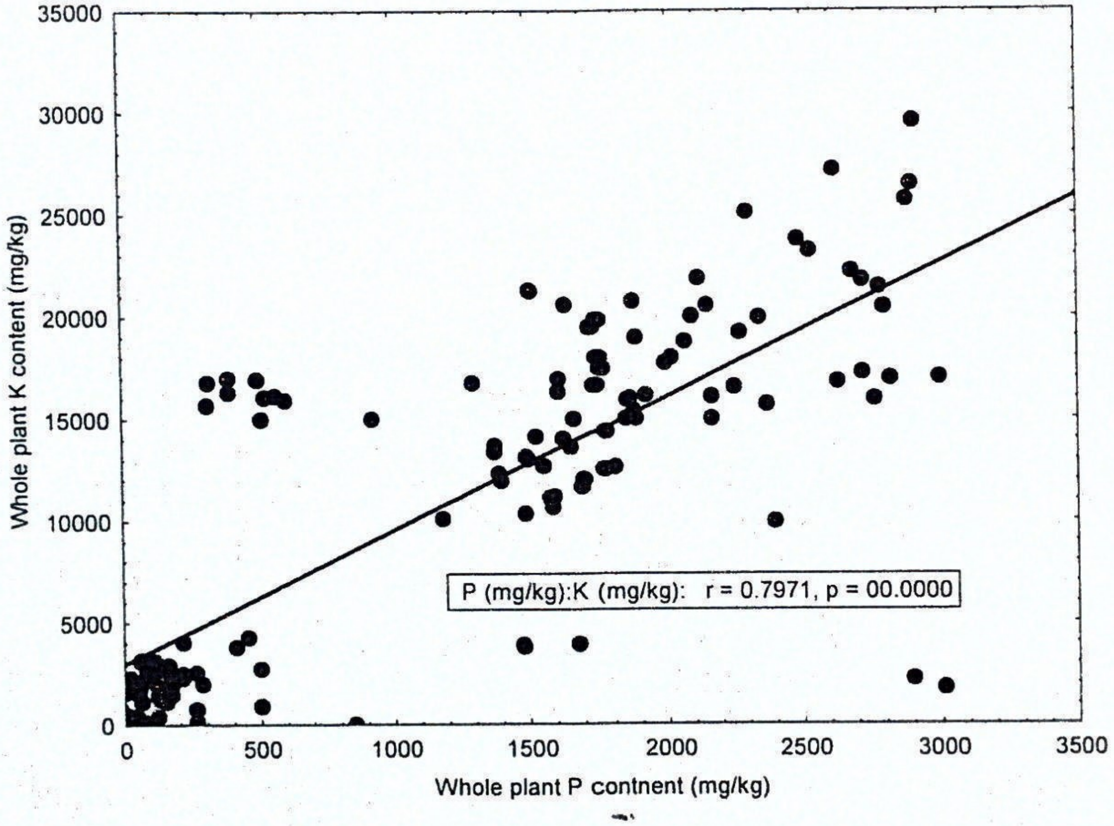

Figure 4.7: Relationship between P content and K content in whole plant.

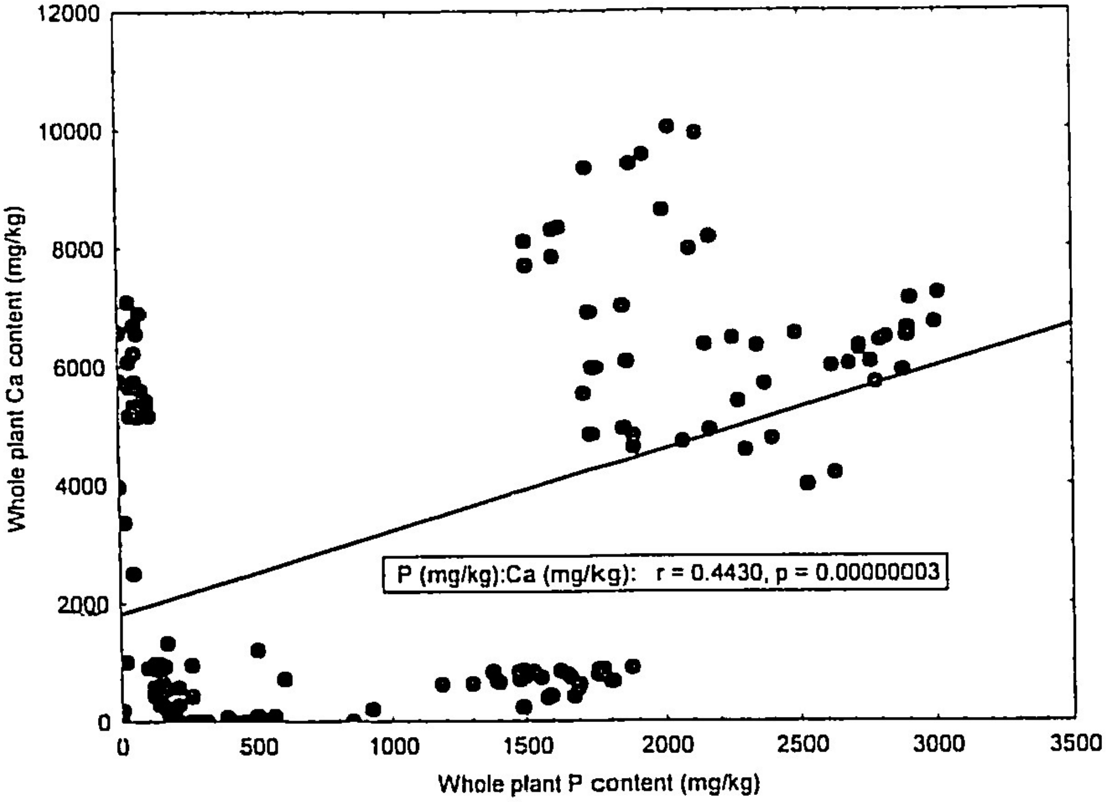

Figure 4.8: Relationship between P content and Ca content in whole plant.

There was a significant positive linear relationship between whole plant P content and whole plant Ca content where ($r = 0.4430$; $p = 0.0000003$). Whole plant Ca content increased with increasing P (Figure 4.8).

4.5 Correlation relationship between phosphorus application rate, dry matter accumulation and macro-nutrients

A positive correlation (linear relationship) between Stover plant P and crop dry matter was established (Figure 4.9) crop dry matter increased with increased P content.

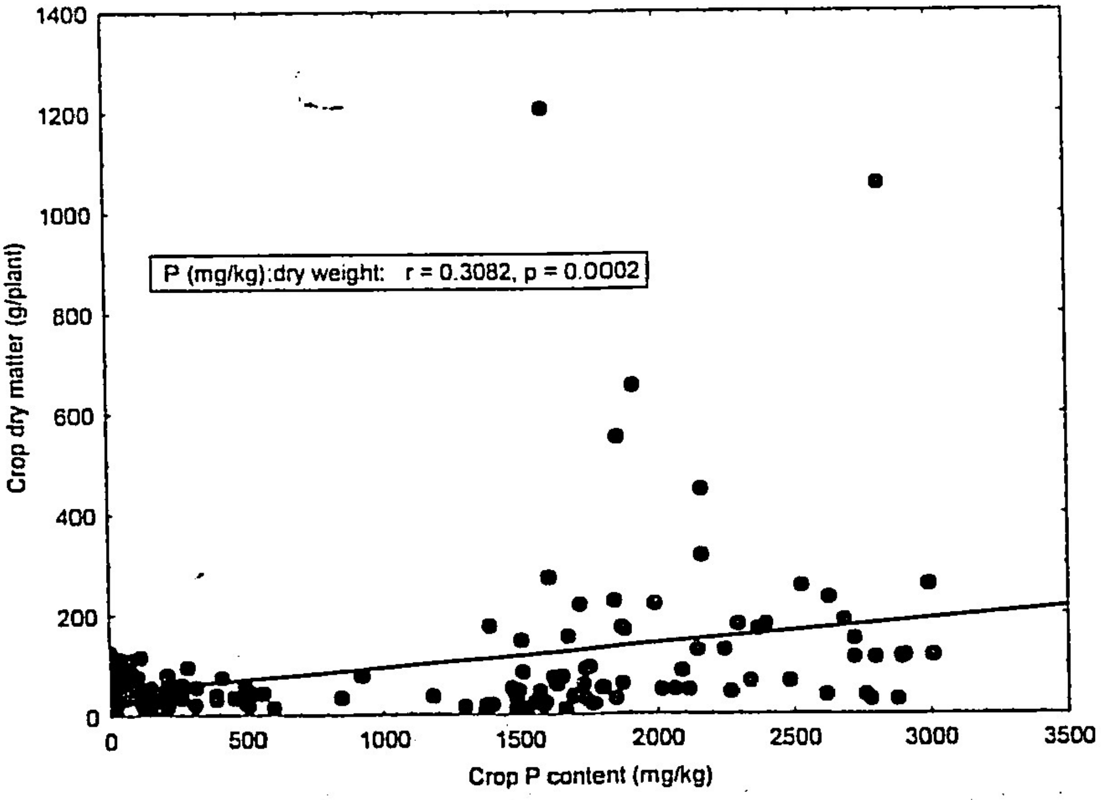

Figure 4.9: Relationship between P content and crop dry matter accumulation in whole plant.

The amount of P in cowpea seed significantly correlated with Mg content (r= 0.7915, and p= 0.0000004 (Figure 4.10. Cowpea seed Mg content increased with increasing seed P content. Similar trends were observed for seed K content (r= 0.7949, and P= 0.000003) (Figure 4.11) and seed Ca (r= 0.5471, and p= 0.057) (Figure 4.12).

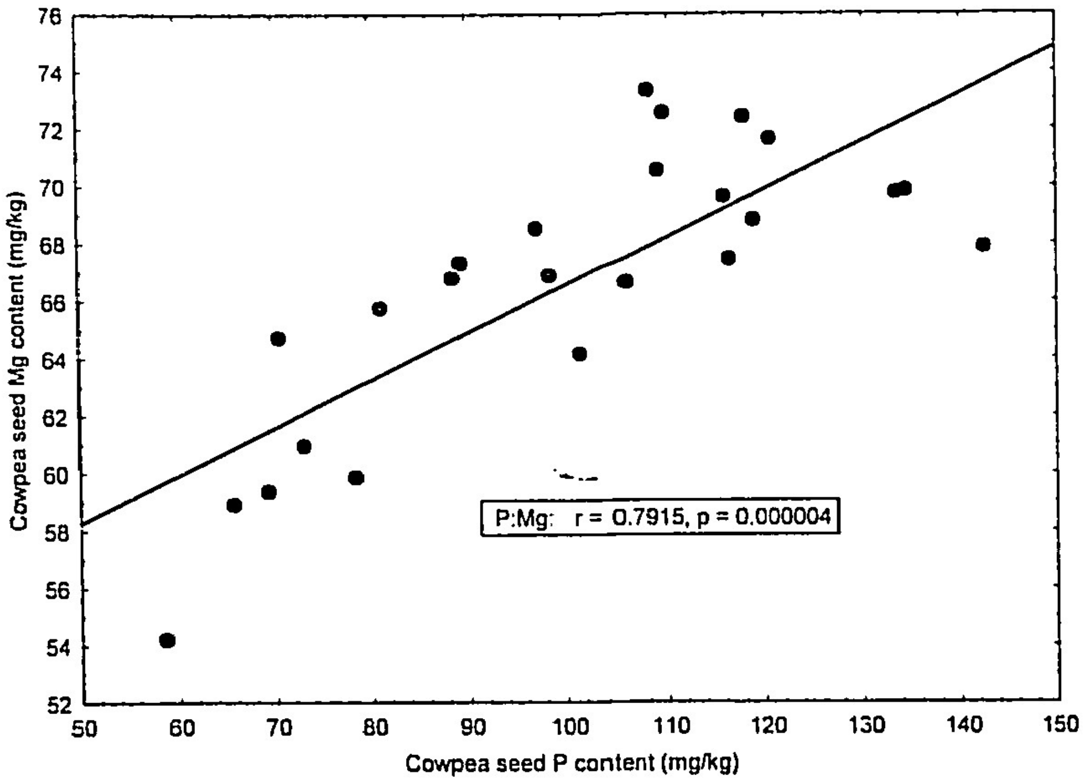

Figure 4.10: Relationship between P content and Mg content in cowpea seeds.

4.6 Correlation relationship between phosphorous application rate and dry matter accumulation

There was a positive and significant correlation between whole plant P content and accumulation of crop dry matter(r = 0.3082; p = 0.0002) as shown by figure 4.9. Crop dry matter increased with increasing P uptake as shown by (Figure 4.9). When P was subjected to correlation with other nutrients, the data revealed a significant positive correlation between whole plant P content and whole plant K content (r = 0.7971; p = 0.0000) Figure 4.7.Stover plant K content increased with increasing P content. The whole plant Ca content (r = 0.4430; p = 0.0000003) (Figure 4.8) also increased with increasing P content.

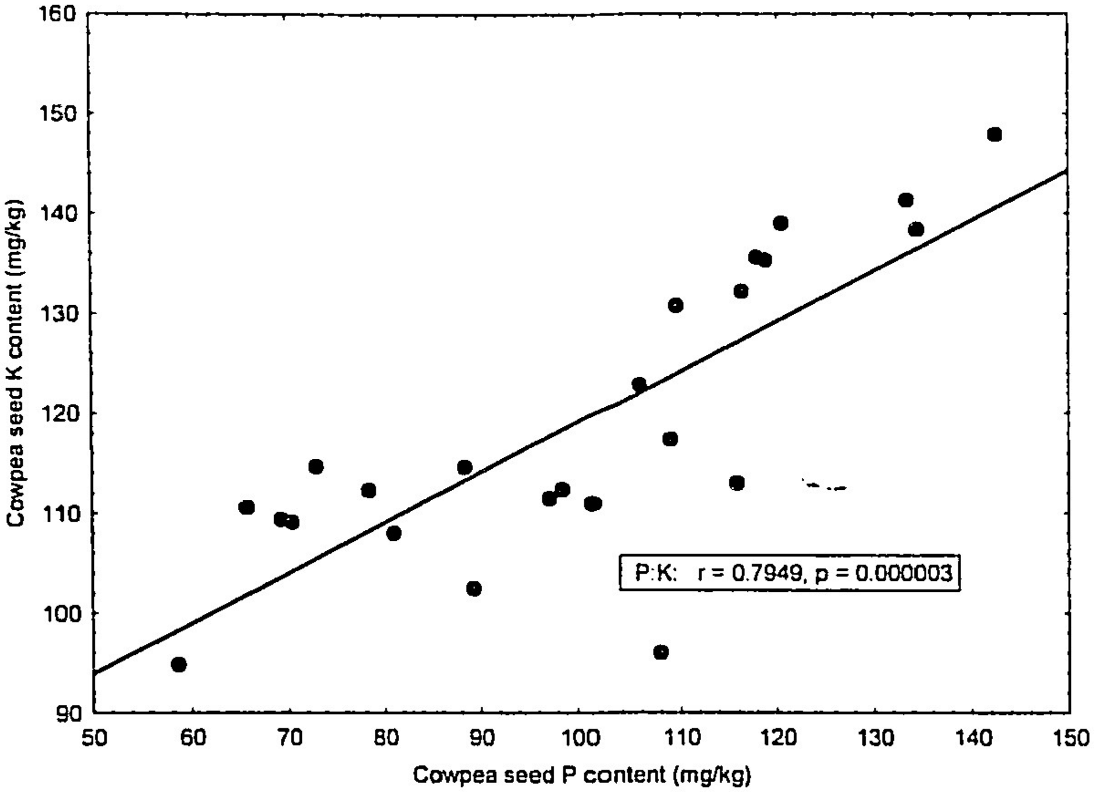

Figure 4.11: Relationship between P content and K content in cowpea seeds.

Another positive correlation relationship was observed between cowpea seed P and cowpea seed K. The illustration as shown by the Figure 4.11 above where (P: K r = 0.7949; p = 0.0000003). High amount of seed P content resulted in high amount of cowpea seed K content.

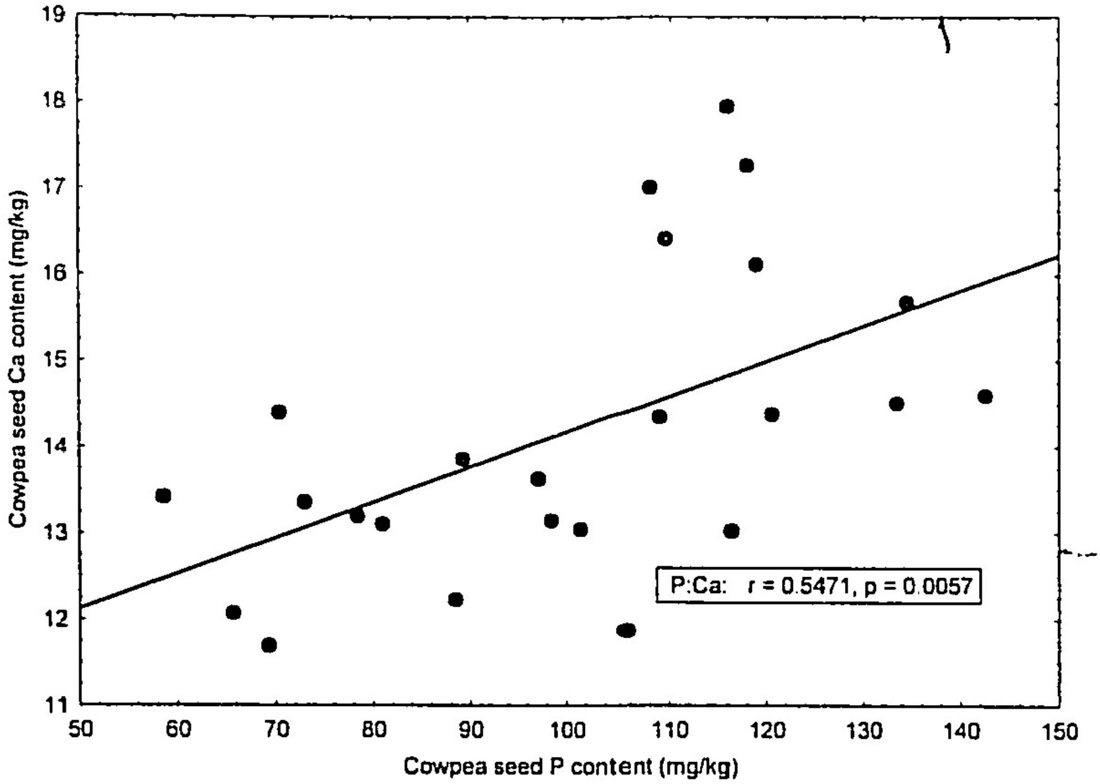

Figure 4.12: Relationship between P and Ca content in cowpea seeds.

4.7 Correlation relationship between phosphorous application rates and micro-nutrients concentration

Micro-nutrients for example Fe, Cu, Mo and Mn were correlated to the P concentration in whole plants and cowpea seeds. Interestingly, all micro-nutrients except Zn showed positive linear correlation. Figure 4.13 shows correlation between P and Mn in whole Plants where increasing whole plant P content resulted in increasing Mn content whole plant (r = 0.8577; and P= 0.0000).

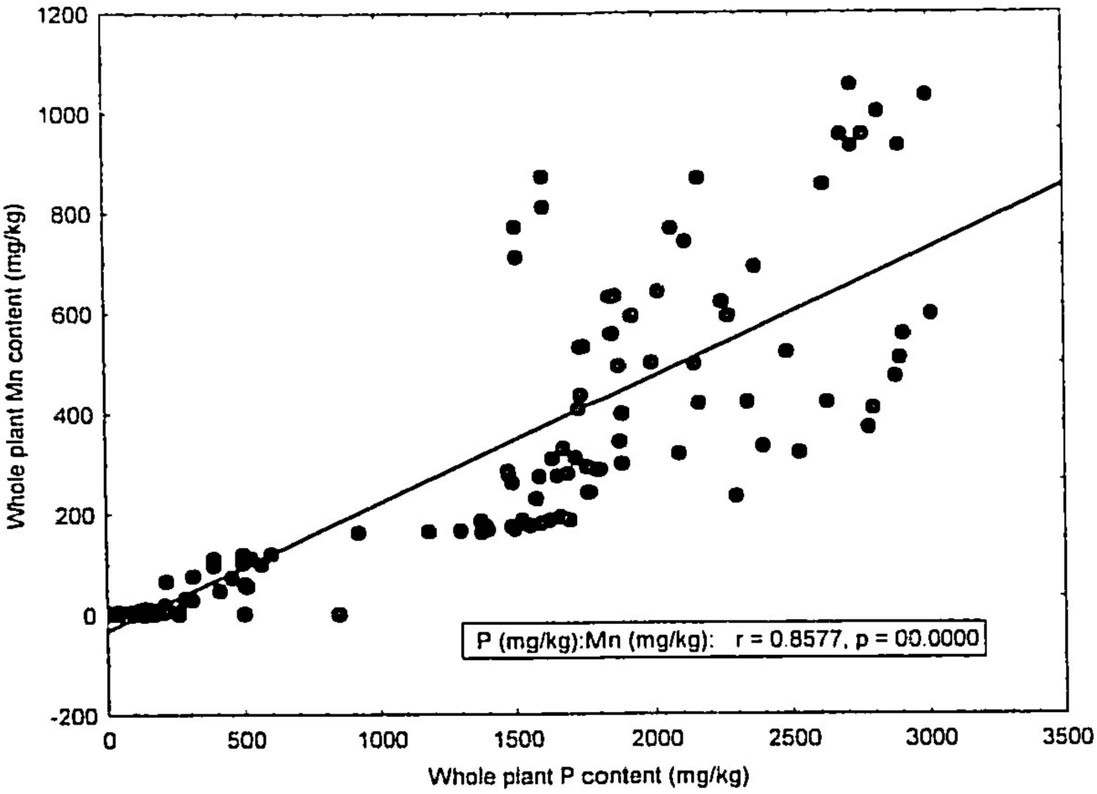

Figure 4.13: Relationship between P content and Mn content in whole plant.

Similarly the relationships of Fe and Mo contents in whole plants with P were statistically significant and showed a positive correlation, with r and p values of 0.6160 and 0.0000 (Figure 4.14) respectively for Mo.

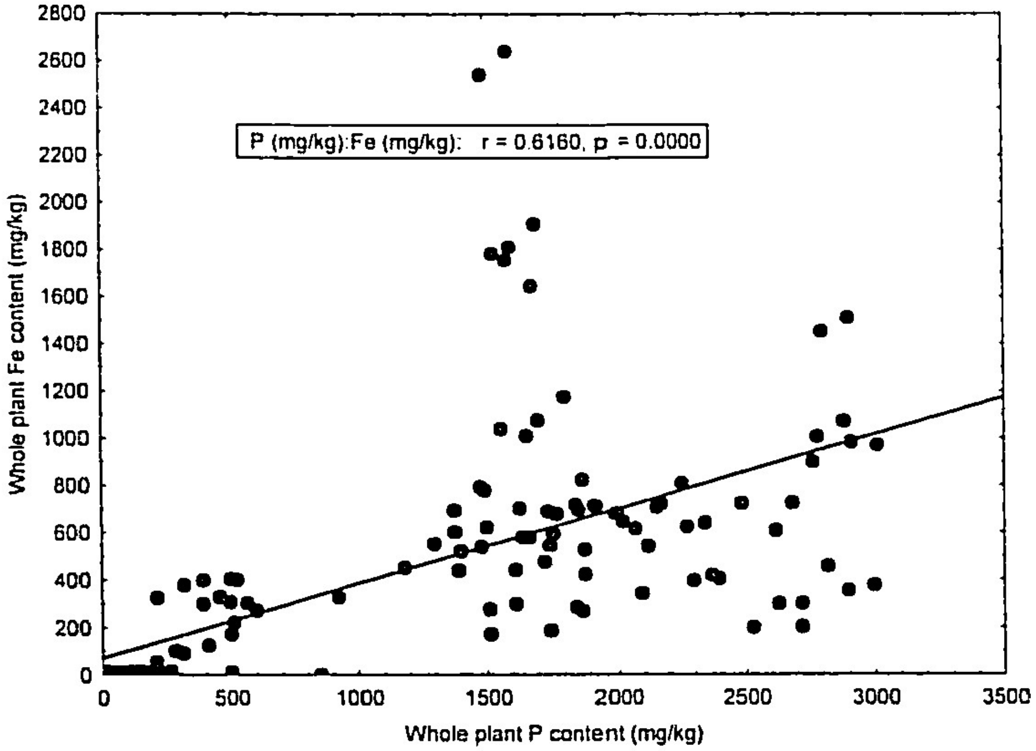

Figure 4.14: Relationship between P content and Fe in whole plant.

Whole plant Fe increased with in increased amount of phosphorus which shows a positive correlation relationship in whole plants where r = 0.6160, p = 0.0000. There is a linear relationship between phosphorus content and Fe content in whole plants.

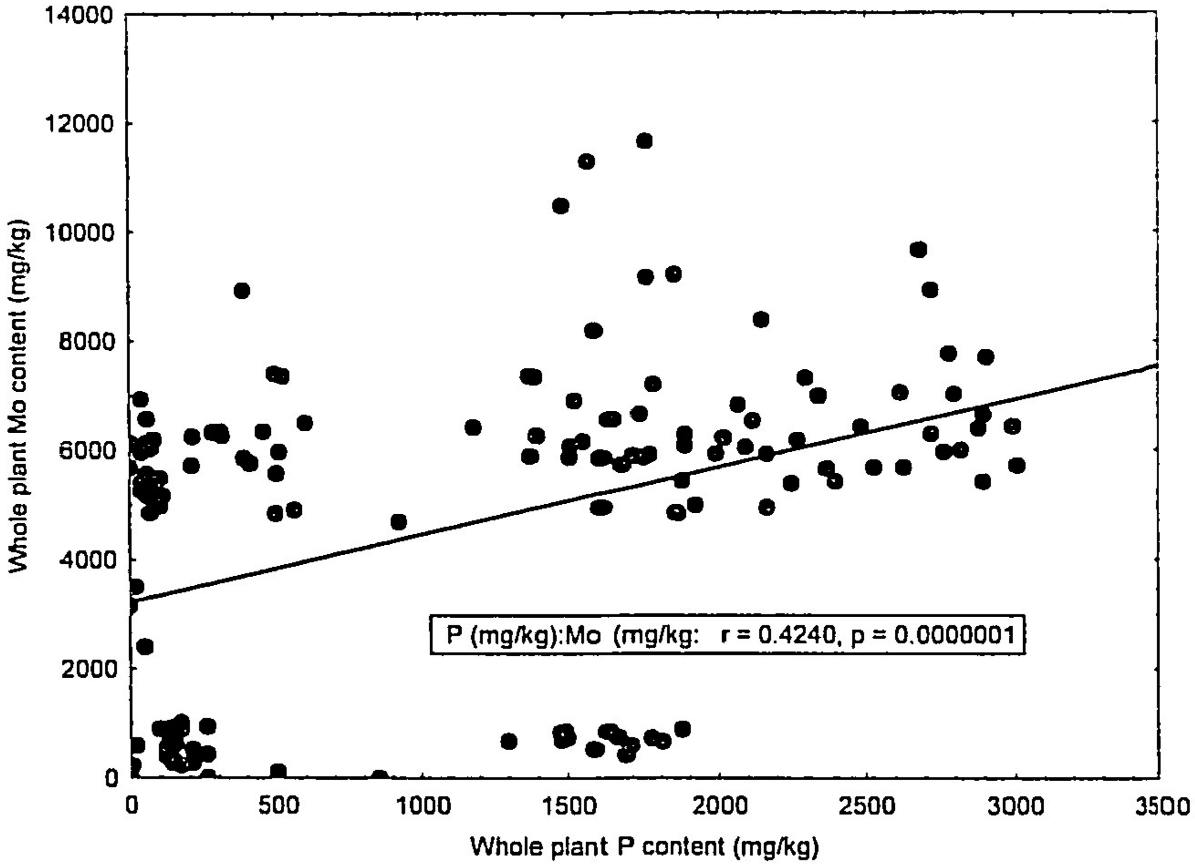

Figure 4.15: Relationship between P content and Mo in whole plant.

Phosphorus high concentration in whole plants resulted in increasing Mo concentration. Increased P showed a positive linear correlation relationship with molybdenum content where r = 0.4240; p = 0.0000001.

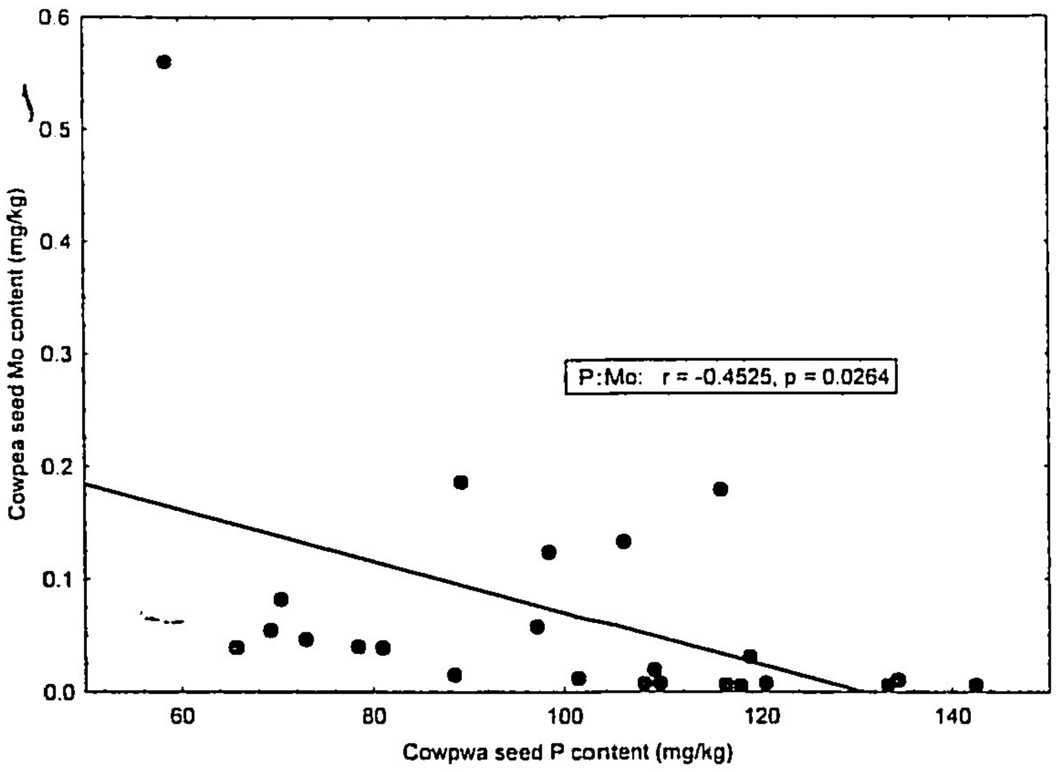

Figure 4.16: Relationship between P content and Mo content in cowpea seeds.

The correlation relationship between cowpea seed Mo, Fe, and Cu with its P concentration were statistically significant and negative in nature (Figures 4.16 – 4.18), thus for all the three micronutrients, their content in cowpea seeds decreased with increasing P content.

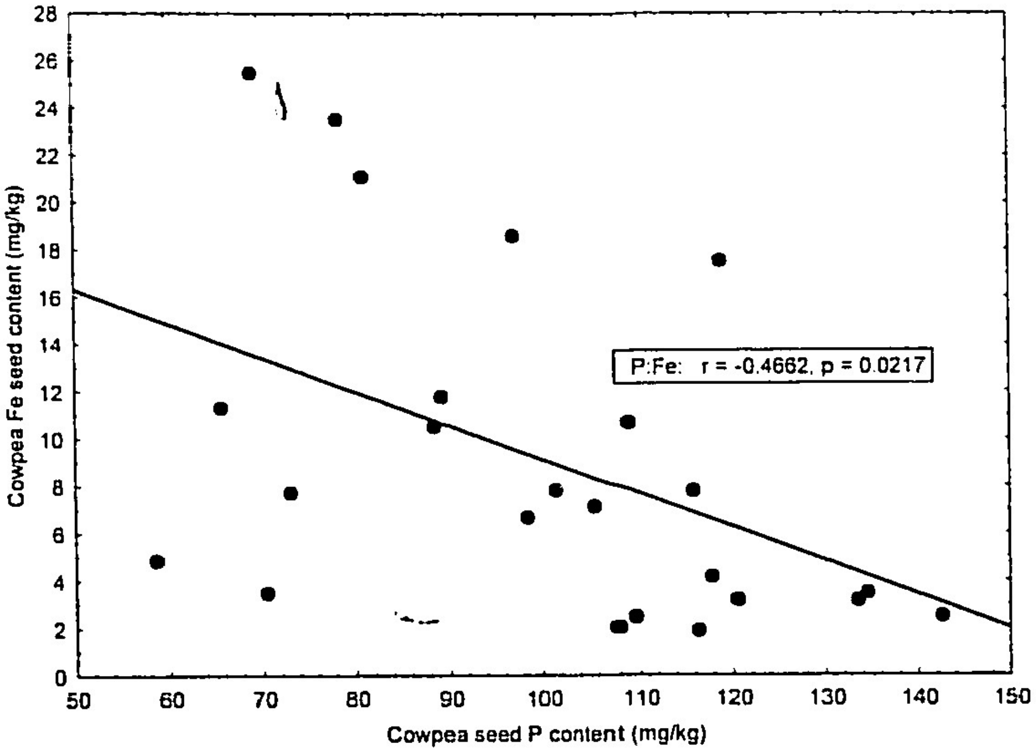

Figure 4.17: Relationship between P content and Fe content in cowpea seeds.

Phosphorus high concentration in seed resulted in less concentration of Fe in cowpea seed hence the inverse correlation relationship. There is a statistically significant inverse relationship between increased P seeds and Fe content in cowpea seed.

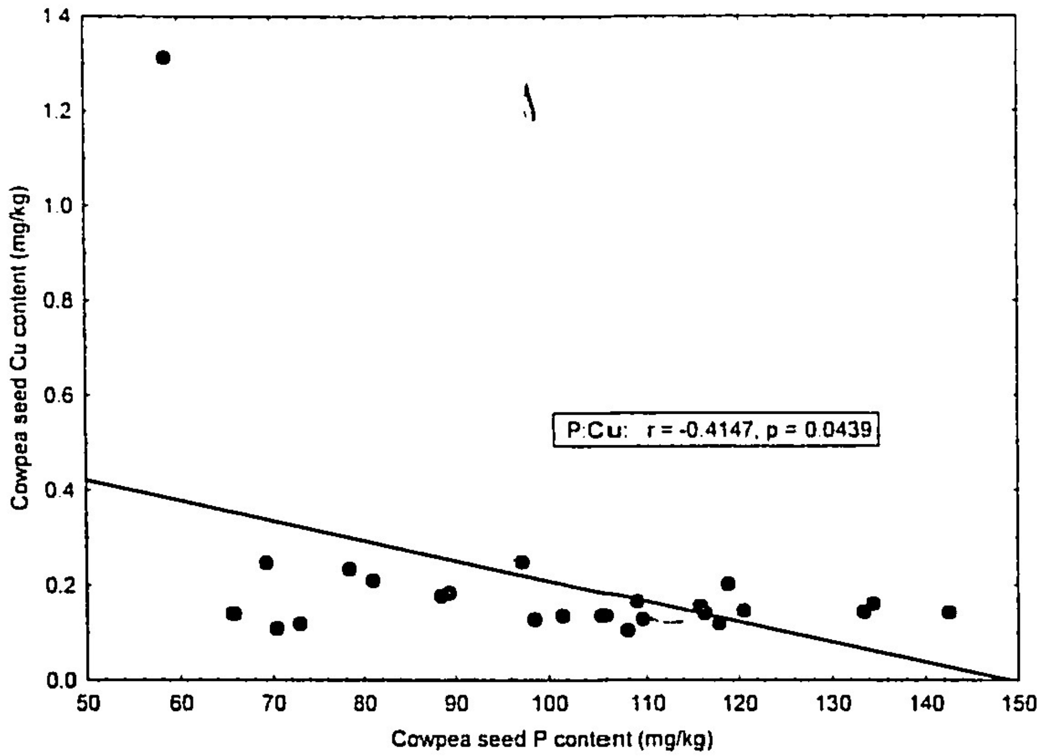

Figure 4.18: Relationship between P content and Cu content in cowpea seeds.

Increased phosphorus content had an inverse relationship with Cu content in cowpea seeds Figure 4.18. The cu content decreased with increasing phosphorus content where r = -0.4147; p = 0.0439 hence, statistically significant negative correlation.

CHAPTER 5: DISCUSSION

5.1 Effects of phosphorous on the growth and macro-nutrients concentration in maize and cowpea Stover

Fertilization of maize and cowpea with different rates of phosphorous ranging from 0–150 P/ha statistically had no effect on plant dry weight (Table 4.1). Despite the lack of statistical significance, dry matter for some treatments, for example, the 100 kg P/ha, were substantially about 35% higher than at 50 kg P/ha. This difference could be significant in cases where stalks are harvested for fodder or silage. It is noteworthy that intercropped cowpea produced the highest whole plant dry matter compared to sole cowpea, with dry matter for intercropped plants being about 2.3 times more than for sole plants. The differences did not however, translate to statistically higher seed yield for intercropped cowpea, though it was 21% higher than from sole cowpea plants (Table 4.4). The difference could be due to low inter row competition for intercropped cowpea, that is, there were fewer cowpea plants per m^2 compared to the sole treatments. Thus, maize and cowpea roots explored different parts of the soil due to differences in their root architecture. Maize and cowpea also showed different nutrient uptake as evidenced by different contents of macronutrients in the dry matter (Table 4.1). Addition of fertilizer P had no effect on the uptake of macro-nutrient. However, significant differences were observed under different cropping systems. For example for all macro-nutrients, sole and intercropped cowpea plants extracted higher levels of nutrients compared to the maize plants, suggesting that symbiotic N fixation induced higher rates of uptake. The suggestion supports the work by Belane *et al*., (2014), who showed that varieties of cowpea which fixed more N_2 through symbiosis accumulated greater amounts of mineral nutrients in their edible leaves than low fixing genotypes. In this study, cowpea was shown to fix N_2 because at inspection, three cowpea plants nodules in each cowpea per treatment plot were inspected and had a bright pink interior, indicating the presence of leghaemoglobin.

5.2 The effect of phosphorous on the growth and micro- nutrients uptake by maize and cowpea plants

Similarly, application of P at different rates had no effect on the uptake of micronutrients such as Mn, Fe, Cu, Zn and Mo (Table 4.2). According to Cassman *et al.* (1981) and Nyoki and Ndakidemi (2014), supplementing soils with P was shown to improve the uptake of micro-nutrients such as Cu, Fe and Mn. The lack of response in the current study could probably be an indication of a higher P fixation capability by the soil. Phosphorus fixation occurs in acid soils such as the soil in the current study (Table 3.1). Under acid conditions, the $H_2PO_4^-$ reacts with the surfaces of insoluble Fe and Mn oxides in a series of reactions that interlock P.

As with macro-nutrients, and whether, the two crops were planted as sole, or intercrop, they had no influence on uptake of micro-nutrient. Numerically, intercropped cowpea accumulated 29% more Mn compared to the monocropped although this difference was not statistically significant. The total Fe content in whole plants was highest in sole maize, which was about five times greater than intercropped maize, about 1.5 times than the other cropping systems.

Like for other micro-nutrients, application of P had no effect on the uptake of Mo. Cowpea, whether planted as mono-crop or intercrop accumulated the highest amount of Mo in its biomass and was about twice higher than in maize. In legumes such as cowpea, Mo serves two functions; i.e. to break down any nitrates taken up from the soil. Non-legumes such as maize also use Mo for this purpose; for leguminous plants, Mo also assists in the biological fixation of atmospheric nitrogen by the root nodule bacteria. The symbiotic bacterial enzyme nitrogenase which is directly involved in the reduction of N_2 to NH_3 comprised of a MoFe protein (Kaiser *et al.*, 2005), thus the root nodules are a sink for Mo. Thus legumes need Mo more than non-legumes, hence the much higher Mo content in cowpea than maize in the current experiment.

5.3 The effect of phosphorous on the seed weight of both monocropped and intercropped cowpea plants

The seed weight was higher in intercropped cowpea compared to monocropped cowpea though statistically there was no significant different among the seed yields (Table 4.4).The seed weight of monocropped cowpea was around 33.13 g per plant which is equivalent to 1546 kg/ha while in intercropped ones it was around 41.66 g per plant which is equivalent to 1944.13 kg/ ha in a plant population of about 74, 000 plants/ ha hence, this can be a better yields for small scale farmers in Botswana who usually harvest not more than 500kg/ha in their rain fed arable fields. These showed that intercropping was productive in cowpea seed yield compared to mono-cropping as it is supported by the findings of Owuor *et al.*, (2002) who emphasized productivity of intercropping being more than growing any component crop alone. The results of intercropping being productive are also in agreement with of Yilmaz *et al.*, (2007) where their results showed higher yields in intercropped cowpea and maize than their sole counterparts' crops.

5.4 Correlation relationship between p concentration and macro/micro-nutrients concentration in plants Stover

The correlation relationship between measured phosphorous concentration and dry matter accumulation as well as measured nutrients uptake was also analyzed. The findings showed positive and significant correlation between P Stover content and accumulation of dry matter. Crop dry matter increased with increased P concentration (Figure 4.7). The results are in agreement with the results of Odundo *et al.* (2009), who reported significant dry matter responses in P application in their case where their trials were on mono-cropped maize compared to control where P was not applied. The data also revealed positive significant correlation between P and other macro-nutrients analyzed as illustrated by the trend for positive correlation relationship with micro nutrients for example Mn, Fe, Mo, and Cu in whole plant material was also observed in relation to P whole plant content where the increased concentration of these micro nutrients increased with increased P concentration in plants stover.

5.5 Correlation relationship between p concentration and macro/micro nutrients concentration in cowpea seeds

Cowpea seeds measured concentration against Mg, Ca and K analyzed indicated positive significant correlation between P seeds and their accumulation in cowpea seeds. Their concentration increased with P concentration. Although increasing P content had linear positive correlation with macro and micro nutrients in whole plant a different scenario in cowpea seeds content of the micro-nutrients for example Mo, Fe, and Cu was observed as the seeds showed a negative linear relationship with increasing P content. In these case, P concentration in seeds resulted in inverse relationship with less accumulation of these micro nutrients in cowpea seeds. The results are supported and in agreement with Marschner (1995) as he observed that for ions with the same valency there is often a negative correlation between the uptake rate and the ion radius although he observed these when comparing Na and K as macro nutrients.

Physiologically during maturity stage the source will have translocated nutrients to the sinks, especially those nutrients that are needed in large amount by plants organs and tissues hence, higher concentration during that stage and (Figures 4.7 – 4.15). The nutritional status of the tissue or plant organ will also be good as it is shown by positive linear relationship. Also, during maturity stage, nutrients that are deficient in an organ or tissue is a result of having been mobilized to small organs during developmental stages hence, a negative relationship illustrated by Figures 4.16 -4.18. This may also be attributed to the soil status where the experiment was of poor agricultural value, that is, low pH (Table 3.1). The low pH may lead to some nutrients being fixed while others may be available (Taiz and Zeiger 2010). Negative correlation at maturity stage may imply that the sink organ has deficiency of that particular nutrient because it may have been mobilized to small tissues before flowering during early developmental growth, and as a result the nutritional status of the sinks (seeds) will be poor.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The application rate of P did not show significant differences in the uptake of all macronutrients tested (N, P, K, Na, and Ca) in the stover plant material and dry matter accumulation. However, all cropping systems have shown significant differences. This was shown by higher weight of mono-cropped maize than the intercropped ones and again higher whole plant dry weight of mono-cropped cowpea compared to their counterparts. Similarly, the P application rate statistically did not show any significant difference in the uptake of all micronutrients tested (Mn, Fe, and Mo) but there were variations again for the different cropping systems. Monocropped and intercropped cowpea showed higher content of Mn and Mo while sole maize and intercropped ones showed the least values. Statistically there was also a significant interaction between P application rate and cropping system for all micro-nutrients analyzed. The intercropped cowpea showed the highest uptake of Fe at application rate of 0 and 150 kg/ha while at application of 0, 100 and 150 kg P/ha sole maize extracted the most Cu. It can be concluded again that P application rate, cropping system and their interaction did not have significant difference in the seed yield of cowpea crops, this may have been because of poor agricultural state of the soil at the site. rates. The study also had revealed that for Ca the mono-cropped cowpea seeds had higher content than the intercropped ones in all P application rates while for Na intercropped cowpea seeds had highest content at 0 kg/ha and 100 kg/ha while mono-cropped had higher uptake at 50 kg/ha and 150 kg/ha. Seed Fe concentration also most increased at 50 P kg/ha and 100 P kg/ha and 150 P kg/ha in intercropped cowpea seeds. Measured concentration of micro nutrients in relation to P content subjected to correlation showed that in both macro- and micro-nutrients in plant Stover there was positive linear relationship. However, cowpea seeds subjected to correlation in relation to seed P and all micro nutrients tested showed inverse relationship where higher seed P content resulted in negative values of correlation coefficients. Therefore, it can be concluded that there was a significant linear positive accumulation of macro and micro-nutrients in relation to increased P content in plants stover. The significant positive correlation which showed linear relationship with P was also observed in cowpea seeds for macro-nutrient while for micronutrients in cowpea seeds inverse linear relationship was noticed in relation to P content. Therefore, in all micro-nutrients studied increased P resulted in negative correlation and less content of these nutrients in cowpea seeds.

6.2 Recommendations

It is recómmended that small-scale farmers in Botswana should practice application of inorganic P fertilizers in intercropping systems of cereals and legume as nowadays Ministry of Agriculture is emphasizing the need to add fertilizers as they provide subsidies. This will be the appropriate agronomic practice because intercropping especially the legume components in the study had accumulated higher dry matter in all cropping systems (monocropped and intercropped) cowpea were more productive than their maize counterparts which were less productive (Table 4.1). The inclusion of cowpea as a legume such as cowpea in cereal intercropping has shown to be productive in the study than growing one cereal crop component alone. Difference in nutrients uptake which can be attributed to crop type has shown efficient use of the nutrients in intercropping system hence the need to practice intercropping legumes with cereals in dry land farming. Cowpeas have shown higher ability to accumulate more DM than maize as well as uptake of nutrients and they can also fix nitrogen which may benefit the next crop in crop rotation systems. Therefore, there is a need for the inclusion of grain legumes such as cowpea with addition of fertilizers such P in dry land farming systems in Botswana. These should be one of the major considerations in cereal legume intercropping for soil improvement in these arable fields. It is also recommended that further research in field trials should be carried out on the effect of phosphorous on intercropped cereals and legumes on dry matter accumulation, seed yield and nutrients uptake as such data is lacking in Botswana. Another recommendation is that soil should be analyzed at the fields to determine the nutritional status of the soil so that correctional

7.0 REFERENCES

Agbenin, J.O. (1996). Comparison of five Isotherms for describing sorption in four savanna Alfisols. Samaru. Agric. Res. 13:3-12.

Agbenin, J.O. (2005). Diagnostic Tests for Soil Fertility Evaluation and Fertilizer Recommendations Applicable to Savanna Soils: A Review. Department of soil science. Faculty of Agriculture. Ahmadu Bello University (U.B.U.). Zaria, Nigeria.pp.29-38.

Barber, S.A. (1985). Soil nutrients Bioavailability: A mechanistic approach, John Wiley and Sons. pp. 204-207.

Bekunda, M. and Woomer, P.L. (1996). Organic resources in management of Banana based cropping systems of the lake Victoria Basin, Uganda Agriculture, Ecosystems and environment, Vol.59, N0 3 pp. 179-180.

Belane, A.K. Mhale, K. C. and Dakora, F. D. (2014). Levels of K, Ca, Mg, in Plants Parts. International Research Journal of Plant Sciences 5 (04), pp 427.

Cassman, K. Munns, D. N. and Beck, D. P. (1981). Phosphorous Nutrition on influence of starch and Sucrose accumulation and activities of cell wall of Clover. J. Exp. Pp 466-467.

Department of Agricultural Research (2004). Field crop reference Book. Ministry of Agriculture. Gaborone, Botswana. 225 pp.

Elton, E. D. and Smith, B. (2002). Environmental science. A study of interrelationship, Mc Graw Hill. 516 pp.

FAO, (2015). Maize crop ITTA, http://www.iita.org/maize of July 16th 2015 accessed on the 17th October, 2015.

Gerke, J. (2000). The quantitative effect of chemical effect of phosphate mobilization by carboxylate anion uptake by single root. The basic concept of soil Parameters, Journal of plant soil science, 163, 207-212.

Hajabasi, T. and Schumacher, M. (1994). Phosphorous effect on root growth development in two maize genotypes. Plant and soil Vol. 158, Issue 1, pp39-46.

Hopkins, W.G. (2005). Introduction to plant Physiology. 2nd edtion, Wiley and sons, University of western Ontario.512 pp.

Islam R, Anyanaba, A. and Sanders, E. (2002). Response of Cowpea (*vigna inguiculata*) to Inoculation with Mycorrhizal fungi and to rock phosphate fertilization. International Institute of Tropical Agriculture Nigeria. No: 36. pp 107-117.

Johnson, J. Allan, D. Vance, C.P. and Weiblen, G.(1996). Root carbon dioxide fixation by phosphorous deficient *Lupinus albus*. Contribution to organic acids exudation by proteoids roots. Plant physiology journal. 112(1031-40).

Kaiser, S. E. Bricker, J. H. Reilein, A. R. Fen, T.D. (2005). Allien Gene Transfer in Crop Plants, Volume 2: Achievements and Impacts https://books.google.cow.bw> books.

Khan,D.F. Peoples, M.B. Chalk, P.M. and Herridge, D.F. (2002). Quantifying below-ground nitrogen of legumes. A comparison of 15N and no isotopic methods. Plant soil. pp 239-289.

Long, L. Shu, m. L. Shu, M. L. Jian, H. S. Lilizou, Z. Xing-Guo, B. Hong-Gang, Z. and Fu-Suo, Z.(2007. Diversity enhances agricultural productivity via Rhizosphere phosphorous facilitation on – phosphorous deficient soils. Laboratory of plant and soil inreaction. Vol. 104 no: 27 pp 11192-11196.

Maasdorp, B.V. and Titterton , M.(1997). Nutritional improvement of maize silage for dairying: mixed crop silages from sole and intercropped legumes and long season variety of Maize. ELSEVIER, animal feed science Technology 69 (1997) 241-261.

Mareshner, H. (1995). Mineral nutrition of higher plants. Second edition, Elsevier academic press, London, UK. 892 pp.

Mengel. K. and Kirby, E.A. (2001). Principles of Plant nutrition, Kluwer Academic Publishers, The Netherlands. pp 3-5.

Mugwira, L.M. and Hague, I. (1991).Variability in growth and mineral nutrition of African clovers. Journal of plant nutrition Vol 14 Nos. 1-16. Addis Ababa, Ethiopia.

Mokwunye. U. (1977). Phosphorus fertilizer in Nigerian savanna. 1. Use of phosphorus sorption isotherm to estimate phosphorus requirement of Maize at Samaru. Tropical Agric. (Trinadad) 54:265-271.

Ndor, E. Dauda, N.S. Abimuku, E.O. Azagaku , E. and Anzaku, H. (2012). Effect of phosphorous fertilizer and spacing on growth , nodulation count and yield of Cowpea (vigna unguiculata (L) walp) souther savanna Agroecological Nigeria. Asian Journal of Agricultural Sciences4(4):254-257, ISSN: 2041-3890.

Nebel, R.J. and Richard T. W. (1998). Environmental science. Prentice Hall. 121 pp.

Niamatulla, M. Sadiq, M. Hajat, H. and Muntaz, M. (2011). Effect of phosphorous application on plants population, number of leaves and yield of green fodder Maize in D. I. Khan, Pakistan. Journal of animal sciences, 21 (11). ISSN: 1018-1081. Pp 94-96.

Nielsen, H.H. Jornsgaard, B. Kiname, J. and Jensen, E.S. (2007). Grain Legume Cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic farming systems. Department of Agricultural sciences, Faculty of life sciences, University of Copenhagen, DK-2630 Taastrup, Denmark.23(1),3-12.

Nielsen N.E. and Jensen, H. (2008). Effect of cropping history and phosphorus source on yield and Nitrogen fixation in sole and intercropped Cowpea-Maize systems. Journal of Crop Science, Volume 8 Issue 1 pp 61-73.

Nour, A. M. Lazim, M. E. and Fattah, A. A. (2000). Effect of nitrogen and phosphorus on growth and yield of Maize. Gezira research station, Agricultural Research Station Corporation, Khartoum North, Ethiopia. pp 19-20.

Nyoki, D. and Ndakidemi, P. A. (2014). American Journal of Plant Sciences 5 (04), pp 447.

Odundo, S.N. Ojiem, O.I. Okalebo, J.R. Othieno, C.O.Laauren, J.G. and Medvecky, B.A.(2009). Effect of phosphorous on survival, phosphorous accumulation and yield of cowpeas (*vigna unguiculata*) varieties across soil fertility gradient in western Kenya. Kenya Agricultural Research Institute. Life sciences. pp 271-278.

Orabi, A.A. and Abdel-Aziz, I.M. (1982). Zinc Phosphorous relationship and effect on some biocomponents of Corn (Zea-mays L.) grown on calcareous. Plant and Soil 69, 437-444.

Ouma, G. and Jeruto, P. (2010). Sustainable horticultural production through intercropping. The case of fruits and vegetable crops: A review. Department of Botany and Horticulture, Maseno University, Maseno, Kenya. 1(5):1098-1105.

Owuor, C. Tenywa, J.S. Woomer, P.L. and Esele, P.(2002). Performance of sorghum legume intercrops in response to row level of Nitrogen. Program and extended abstracts. FORUM working. pp 431-439.

Page,A. L. Miller, R. H. Keeney, D. R. (1982). Methods of Soil Analysis: Chemical and Microbiological Properties, 2. Auf. 1184 s., American Soc. of Agronomy (Publi.). Madison, Wisconsin, USA.

Pieter, P. Huybrighs, M. Diels, J. Abadooi, R. Smolders, E. and Merckx, R. (2007). Does th enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability. Soil Biology and Biochemistry, International Institute of Tropical Agriculture (IITA), Oyo Road, Ibadan, Nigeria.Vol. (39) pp. 2555-2566.

Pule- Meulengberg, F.(2014). Root- Nodule Bacteria of legumes growing in semi- arid African soils and other areas of the world. Bacterial diversity in sustainable Agriculture, Department of Crop Science, Botswana college of Agriculture, Springer international publishing, Botswana. pp 101-130.

Rashid, M. and Iqbal, M. (2011). Effect of phosphorous fertilizer on the yield and quality of maize (Zea-mays L.) fodder on clay loam soil. Directorate of livestock Research Institute,Bahadurnagar, Okara. The Journal of animal and plant science, 22(1): ISSN: 1018-7081. pp 199-203.

Reddy, M.S. and Wiley, R.W.(1981). Growth and resource use studies in an intercrop of pearl millet/groundnut. Field crop Res.4; 13-14.

Rodger, F. and Dennis, R.P.(1993). Developing an effective Southern pea and sweet corn crop system. Hort. Technology 3(2): pp 178-184.

Rukazamba, N.C. Gold, S. Gowen, O. and Ragama, P. (2001). The influence of crop management on banana weevil, populations and yield of high cooking in Uganda, Bulletin of entomological research Vol. 92 pp413-421 C.U.P.

Sakala, W.D. Cadsch, G. and Giller, K.E.(2000). Interaction between residues of maize pigeon pea and mineral N fertilizer during decomposition and N mineralization. Soil Biology and biochemistry 32: 699-706.

Snapp, S.S. Mafongoya, P.L. and Waddington, S. (1998). Organic matter technologies for integrated nutrient management for smallholder cropping systems of southern Africa. Agriculture, Ecosystems and Environment 71 pp185-200.

Statistics Botswana, 2007 and 2008 (2012). Agricultural Survey Report, Agricultural Statics unit, Ministry of Agriculture, Division of Policy Research and Statistics, Gaborone. pp327.

Taiz. L. and Zeiger, E.(2010). Plant Physiology. 5^{nd} Edition, Library of Congress, 23 Plumtree Road, Sunderland, MA, 01375 U.S.A. pp 782.

Vesterager. J.M. Nielsen, N.E. and Jensen, H.H. (2007). Nitrogen budget in crop sequences with or without phosphorus- fertilized cowpea in the maize- based cropping systems of semi-arid eastern Africa. African journal of Agricultural Research Vol. 2(6), pp. 261-268.

Willie. J. (1991). Physical properties moisture regime and crop production. A case study on luvisol in Sebele. AG:BOT/85/011, mapping and advisory services, Botswana. pp 48.

Yilmaz. F. Atak, M. and Erayman, M. (2007). Identification of advantages of maize legume intercropping over Solitary cropping Through competition of indices. Department of field crops. Faculty of Agriculture, Vol.32. Mustafa. Kema University, 31034, Hatary. Turkey. pp.111-119.