EVALUATION OF DI-AMMONIUM PHOSPHATE (DAP) AS AN ALTERNATIVE BASAL DRESSING FERTILIZER TO COMPOUND D FOR MAIZE PRODUCTION ON FOUR ZAMBIAN SOILS

BY

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A dissertation submitted to the University of Zambia in partial fulfilment of the requirements of Master of Science degree in Agronomy (Soil Science)

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DECLARATION

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This dissertation of Mr. Mwenya Mulenga is approved as fulfilling part of the requirements for the award of the Degree of Master of Science in Agronomy (Soil Science) by the University of Zambia

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ABSTRACT

Maize is Zambia's staple food crop, grown by farmers across the country. It is a high nutrient demanding crop that requires adequate amounts of N, P K and other nutrients to obtain economic yields. The recommended basal dressing fertilizer for small scale farmers in Zambia is Compound D, (10: 20: 10) which supplies N, P and K to crops. On soils deficient in N, P, and K it is the ideal fertilizer. Studies have shown that most Zambian soils are deficient in N and P, but not so with K. It is also known that maize yields rarely increase in response to additions of K on soils with high levels of K. The rationale behind using NPK fertilizers on soils with high K can thus be questioned. Fertilizers such as Di-ammonium Phosphate (DAP) (18: 46:0) which only supply N and P, can be alternatives to Compound D on such soils. Greenhouse pot trials and field crop trials were conducted on four P deficient soils to assess the potential of using DAP to replace Compound D for growing maize. The soils comprised a Phaeozem, an Acrisol, and two Lixisols, from Chilanga, Rufunsa, Chongwe and Chibombo districts respectively in Agro-ecological Zone II. Pot trials were conducted in Lusaka, and field trials on-farm, in the mentioned districts. The Phaeozem and Acrisol had high levels of soil organic matter (SOM), while the Lixisols had moderate levels. Furthermore, the Phaeozem, Acrisol and one Lixosol had high levels of K, while one Lixisol had low levels of K. Pot trials were laid out in Completely Randomized Design with 7 rates of DAP of 0, 25, 50, 75, 100, 125 and 150 kg/ha and 200 kg Compound D/ha in triplicate. Maize plants were grown for six weeks. The above ground biomass was harvested, dried and weighed to obtain the dry matter yield. The field trials were laid out in a Completely Randomized Block Design with 8 treatments in quadruplicate. Treatments were the same as those used in the pot trials, with the 25kg DAP/ha treatment replaced by 200 kg DAP/ ha. The maize was grown to maturity, and the grain yield obtained and recorded. Maize dry matter and grain yields from the trials were subjected to Analysis of Variance and comparison of means. The dry matter and grain yields were further used to calculate the Relative Agronomic Effectiveness (RAE) of DAP compared to 200 kg Compound D/ha. Results of the pot trials showed that DAP was as effective as Compound D in producing maize dry matter on the Phaeozem, Acrisol and the Lixisol with high levels of K. On Lixisols with low K, DAP was less effective than Compound D in producing maize dry matter. Results of field crop trials, showed that 100 kg DAP/ha was as effective as 200 kg Compound D/ha on all four soils in producing maize grain yield. The effectiveness of DAP was greater on soils with high K and SOM than on soils with moderate to low SOM. Results of this study have demonstrated that DAP at 100 kg/ha can substitute 200 kg Compound D/ha as a basal dressing fertilizer for producing maize on soils with low P and moderate to high amounts of K and SOM in Zambia.

Key words: Maize, Compound D, Di-ammonium phosphate, RAE, phosphorus, potassium, soil organic matter.

DEDICATION

To my mother and father for their never ending love, support and encouragement.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
ANOVA	Analysis of Variance
CRD	Completely Randomized Design
CSO	Central Statistical Office
DAP	Di-ammonium Phosphate
DMRT	Duncan's Multiple Range Test
DMY	Dry Matter Yield
FAO	Food and Agriculture Organization
FISP	Farmer Input Support Programme
FSP	Farmer Support Programme
HI	Harvest Index
IFPRI	International Food Policy Research Institute
IFA	International Fertilizer Association
IFDC	International Fertilizer Development Corporation
IITA	International Institute for Tropical Agriculture
JAICAF	Japan Association for International Collaboration of Agriculture and Forestry
MACO	Ministry of Agriculture and Cooperatives
MGY	Maize Grain Yield
OC	Organic Carbon
RAE	Relative Agronomic Effectiveness
SOM	Soil Organic Matter
UNZA	University of Zambia
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture
ZARI	Zambia Agricultural Research Institute

CHAPTER ONE: INTRODUCTION

1.1 Background

According to the International Institute of Tropical Agriculture, IITA (2007), maize (*Zea mays* L.) together with rice and wheat are the most important crops in the world, while in the sub-Sahara African region, maize has been ranked as the most important crop. In Zambia, according to the Food and Agriculture Organization, FAO (2011), maize has been ranked as the main cereal crop. It has also been ranked as the number one crop commodity in terms of value and follows sugarcane in terms of the tonnage of production and is the fourth exported crop product after sugar, cotton, and tobacco.

Maize in Zambia is grown in all the agro-ecological regions, but is predominantly produced in Agro-ecological region II, commonly referred to as the medium rainfall region. The region is characterized by a mean annual rainfall of between 800 and 1000 mm. The Zone covers 48 percent of the country with rainfall and growing season in this area being moderate in supporting agricultural products like maize, tobacco, groundnut, sunflower, soybean, wheat, vegetables, sweet potato, cotton and the rearing of livestock such as cattle, goats and poultry. This is the area where commercial production has been concentrated because of relatively good ecological conditions and services. The region presents highest potential for growth in the agricultural sector.

According to the statistics provided by MACO-CSO (2010), it has been stated that the potential grain yield of maize in Zambia is estimated at about 12 tonnes per hectare but the average grain yield on most small scale farmer's fields is about 1.5 tonnes per hectare. This low yield according to MACO-CSO (2009) is mainly attributed among other factors to the low fertility status of most cultivated soils used for growing maize in the country. In most countries of the world, low soil fertility has been identified as a major factor hindering maize productivity, and therefore the application of fertilizers to supplement the generally low levels of nutrients in soils used for maize production is necessary to obtain good crop yields.

According to Xu *et al.* (2009), improving maize productivity has been the major goal of the Zambian government's agricultural policy over the past several decades. This policy has focused on providing fertilizer subsidies and targeted credit programs to stimulate small scale farmers' crop productivity, to enhance food security and reduce poverty. In line with the stated policy guide, the Zambian Government in 2002 introduced the Fertilizer Support Program (FSP), later called the Farmer Input Support Program (FISP).

The original objective of the FSP was to supply subsidized fertilizers to small scale farmers to assist them increase maize production to ensure household food security. Later the scope of the program was broadened to include a provision of hybrid maize seed in addition to the fertilizers and the name of the program was consequently changed to the Farmer Input Support Program (FISP). The inputs supplied under the FISP Program include basal and top dressing fertilizers and hybrid maize seed. The basal dressing fertilizer supplied is Compound D while the top dressing fertilizer is urea. Compound D contains nitrogen (N), phosphorus (P) and potassium (K), in concentrations of 10 % N, 20 % P_2O_5 and 10 % K_2O. These correspond to concentrations of 10 % N, 8.7 % P and 8.3 % K. The top dressing fertilizer urea, on the other hand contains 46 % N.

In Zambia, the agriculture extension service recommends a fertilizer application rate of 200 Kg Compound D as basal dressing per hectare and 200 kg Urea as top dressing per hectare for maize production for small scale farmers. This corresponds to a nutrient application rate of 112 kg of N per hectare, 17.4 kg P per hectare and 16.6 kg K per hectare. However, these nutrient application rates apply across the different soil types and do not take into account the individual fertility status of the soils. The premise is that, to obtain good grain yields maize requires an adequate supply of the primary nutrients N, P and K.

The key macronutrients required in large quantities by maize are N, P and K. According to Yayock *et al.* (1988) the fertilizer requirements for maize grown in tropical conditions are about 100 -120 kg N /ha, 40 kg P/ha and 50 kg K/ha. The FAO and IFA (2000) report nutrient requirements for maize to be 72 – 120 kg N/ha, 16 - 22 kg P/ha and 45 -100 kg K/ha for targeted maize grain yields of 3000 to 6000 kg/ha. Landon (1991) reports maize nutrient requirements of 100 -200 kg N/ha, 50 - 80 kg P/ha and 60 -100 kg K/ha. Besides N, P and K, maize also requires adequate amounts of the macronutrients calcium, magnesium and Sulphur.

In order for maize to grow to its full potential, Lafitte (1991), has stated that maize will require at least 500-700 mm of well distributed rainfall during the growing season. In addition Du Plessis (2003) has also stated that as maize is a warm weather crop and should not be grown in areas where the mean daily temperature is less than 19 ºC or where the mean of the summer months is less than 23 ºC. Although the recommended minimum temperature for maize germination is 10 ºC, germination will be faster and less variable at soil temperatures of 16 to 18ºC with the critical temperature detrimentally affecting yield being approximately 32ºC. It has been further stated by Du Plessis (2003), that frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage.

In addition to the favorable climatic conditions for maize production, IFDC *et al.* (2012), has indicated that substantive use of fertilizer is a prerequisite for the success of efforts to improve agricultural productivity and hence increase agricultural output and farm income in Africa. No country in the world has achieved substantive agricultural growth without the use of fertilizers. However, fertilizer use rates in Africa are low and misapplied. Declining nutrient consumption, low and misapplied fertilizer application rates have translated into low cereal crop yields per hectare for Africa. Zambia is not an exception to these attributes towards fertilizer use as most small scale farmers are currently using fertilizers for general crop production and on maize in particular.

Maguire *et al.* (2009), have recognized that matching fertilizer application rates to crop needs is an essential component of optimizing crop production and different crops in separate fields will require varying rates of the major nutrients i.e. nitrogen (N), phosphate (P_2O_5), and potassium (potash, K_2O) due to variations in soil types, soil test phosphorus and potassium levels, and nutrient ranges of different crops.

Of the macro nutrients essential for plant growth, N and P have been reported to be the most limiting nutrients for maize production in most Zambian soils. Potassium is often not as limiting as N and P for maize production in many Zambian soils. In a study conducted on 124 surface soil samples from 3 districts of Southern Province in Zambia, Lungu *et al.* (2010) reported that all or 100 % of the soils were deficient in N while 83 % were deficient in P and only 27 % were deficient in K for maize production. And in a related study conducted in the Eastern Province of Zambia on 288 surface soil samples from 9 districts, it was found that only about 9 % were deficient in K, Shitumbanuma and Chikuta (2013) clearly agreeing with the statement that the most limiting macro nutrient to maize production on most Zambia agricultural soils is rarely K but rather N and P.

1.2 Statement of the Problem

Empirical evidence shows that soils differ in their chemical and physical characteristics. In most soils N and P are deficient and in others N, P and K are deficient. Therefore, the use of (N, P, K) as a basal dressing fertilizer for maize production was intended to address possible occurrences and deficiencies of N, P and K. This research study aimed at comparing the agronomic performance of di-ammonium phosphate (DAP) and Compound D as basal dressing fertilizers for maize production on four selected Zambian soils.

1.3 Objectives

1.3.1. Main Objective

The main objective for the study was to assess the agronomic performance of di-ammonium phosphate fertilizer as an alternative to Compound D fertilizer as a basal dressing fertilizer for maize production on four selected Zambian soils using small-scale farmer's practices

1.3.2. Specific Objectives

The specific objectives for the study were:

1. To determine the effect of different rates of di-ammonium phosphate fertilizer on the dry matter yield of maize under greenhouse conditions as compared to 200 kg/ha Compound D application
2. To determine the effect of different rates of di-ammonium phosphate fertilizer on the grain yield of maize under field conditions as compared to 200 kg/ha Compound D application

1.4 Research Hypotheses

The Research Hypotheses in this study were:

1. The Relative Agronomic Effectiveness of 100 kg DAP/ha compared to 200 kg Compound D/ha on the soils used in the study based on maize dry matter yield is not less than 100 %.
2. The Relative Agronomic Effectiveness of 100 kg DAP/ha compared to 200 kg Compound D/ha on soils used in the study based on maize grain yield is not less than 100 % .

The Null Hypotheses tested in the study were:

1. The Relative Agronomic Effectiveness of 100 kg DAP/ha compared to 200 kg Compound D/ha on the soils used in the study based on the dry matter yield is less than 100 %.
2. The Relative Agronomic Effectiveness of 100 kg DAP/ha compared to 200 kg Compound D/ha based on the soils used in the study based on maize grain yield is less than 100 %.

The rate of 100 kg DAP/ha was selected as the appropriate rate for evaluating the effectiveness of DAP as a potential substitute for the recommended rate of 200 kg Compound D/ha, because 100 kg of DAP (assuming a composition of 18 % N and 46 % P_2O_5) has the closest N and P contents to 200 kg Compound D. The 100 kg DAP/ha rate corresponds to about 18 kg N/ha and 46 kg P_2O_5, which is close to 20 kg N/ha and 40 kg P_2O_5/ha contained in 200 kg Compound D.

1.5 Significance of the Study

Maize is the staple crop in Zambia cultivated throughout the country and by all categories of farmers. The farming community in Zambia is categorized into three major groups, namely commercial farmers, emergent farmers and small scale farmers. More than 60% of maize production in Zambia is contributed by small scale farmers. However, despite their significant contribution to maize production, small scale farmers are the most vulnerable financially and mostly rely on subsidized inputs from the Government through the Farmer Input Support Programme (FISP).The FISP Programme provides basal dressing and top dressing fertilizers and hybrid maize seed to farmers. The basal dressing fertilizer provided is Compound D while the top dressing fertilizers is Urea. Results of several studies on the nutrient status of soils in Zambia have shown that many soils have sufficient levels of K for maize production. On such soils, Compound D fertilizer, may not be the appropriate basal dressing fertilizer. Further, the application of Compound D fertiliser to soils with adequate to high levels of K increases the cost of producing the crop. This study was undertaken to assess the potential of using di ammonium phosphate as an alternative basal dressing fertilizer to Compound D for maize production on selected soils.

CHAPTER TWO: LITERATURE REVIEW

2.1 Status of World Maize Production

According to Verheye (1990), maize (*Zea mays* L.) is the most important cereal crop in the world after wheat and rice. It is grown in more diverse regions than any other crop with vast genetic differences occurring among the kinds of maize grown in these different areas. Maize crop is cultivated from northern Europe and Russia to South Africa, eastward through Asia, the Himalayas, China, Southeast Asia and the Pacific Islands, westward from Puerto Montt in Chile to New Brunswick in Canada. According to Ranum *et al.* (2014), maize is grown throughout the world with the United States, China and Brazil being the top three producers.

Kumwenda *et al.* (1995), reported that in Southern and Eastern Africa where maize is the dominant crop grown by smallholder farmers, it is grown from sea level in the coastal zones of Mozambique and Tanzania to elevations above 2400 m. They further stated that maize accounted for 60 % or more of the cultivated area in Malawi, Zimbabwe and Zambia and was almost as dominant in Mozambique, Tanzania and Kenya. Smale and Jayne (2003) reported that maize occupied 75 % or more of the cultivated area under cereal crops in Kenya, Malawi, Zambia and Zimbabwe, and that, Nigeria and Ghana were the largest producers of maize in Western Africa, although the average percentage of maize consumption in West Africa was lower than Southern Africa.

It is evident that maize is an important crop worldwide whose decline in production would adversely affect the wellbeing of a large number of people. Rosegrant *et al.* (2007) projected a doubling in the demand for maize by 2050, due to the increasing demand for its use in livestock feed and as a source of bio-energy. However, despite this projected need for increased maize production, Rosegrant *et al.* (2009) reported a significant decline in maize yields for many farmers in Africa in the first decade of the 21st Century. They attributed the decline amongst other factors to the adverse climatic condition associated with that posed a real challenge to meeting the projected increase in the global demand for maize.

2.2 Maize Production in Zambia

Maize (*Zea mays L.*) is the staple cereal crop in Zambia and the most extensively cultivated crop among all the categories of farmers in its ten provinces. According to a report by the Central Statistics Office (CSO) and the Ministry of Agriculture and Cooperatives (MACO/CSO.2011) small scale farmers in Zambia contribute in excess of 60 % to the total maize production in the country.

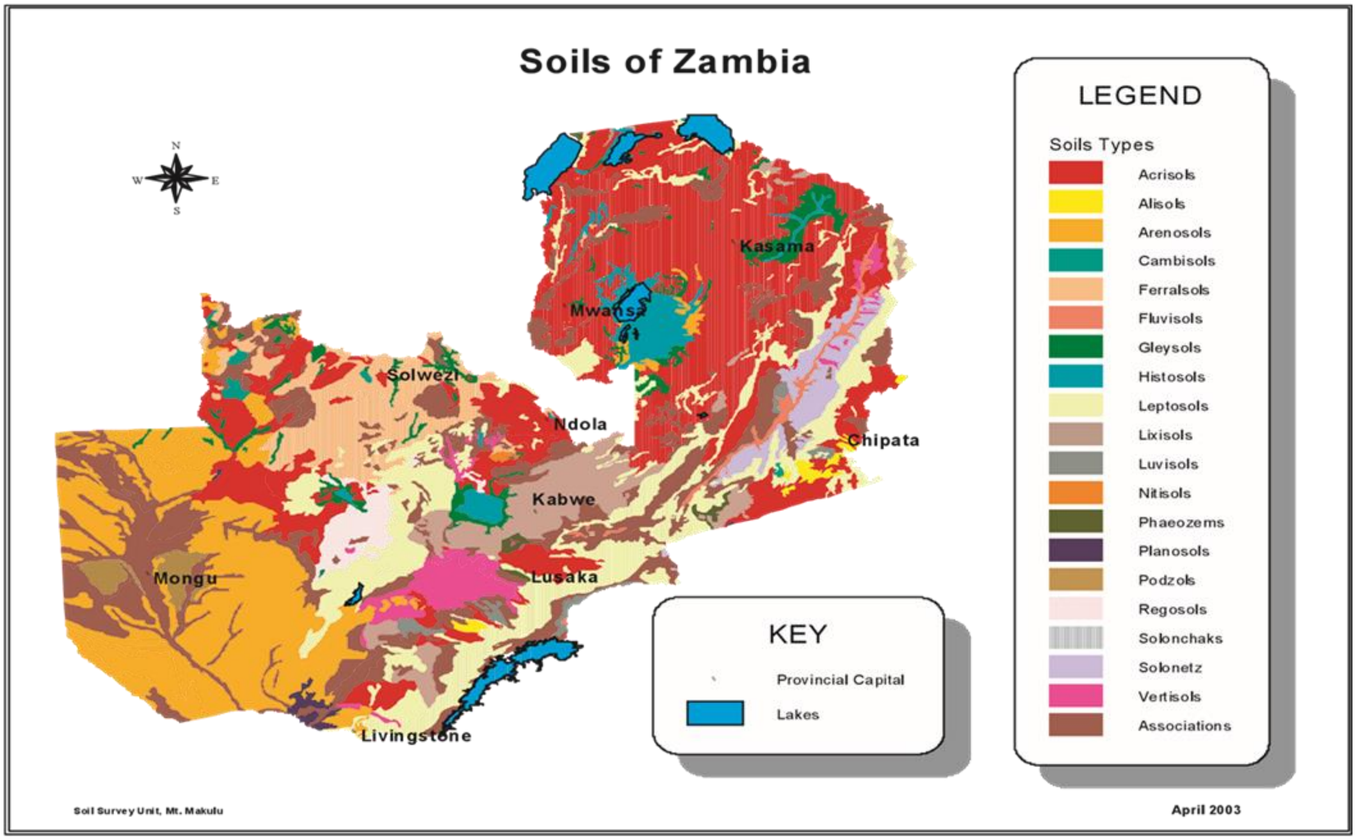
Despite the great proportion of the total production on maize in Zambia, contributed by small scale farmers, their productivity or average yield is generally low. In addition, Xu *et al.* (2009) reported that the average yield of maize among small scale farmers, in Zambia is low and ranged from 1.2 and 1.8 metric tonnes per hectare in the first decade of the 21^{st} century. The reported yields are consistent with those with the average maize yields for African small scale farmers.

2.3 Soils of Zambia and the Status of Fertilizer Use

2.3.1 Soils

Zambia is endowed with a wide range of soils. According to the soil map of Zambia of 1990 (Figure 1), compiled by the Soil Survey Unit of the Zambia Agriculture Research Institute Muchoka (1990), Zambia has about 19 of the major soil units of the FAO legend. The soil units include; Acrisols, Alisols, Arenosols, Cambisols, Ferralsols, Fluvisols, Gleysols, Histosols, Leptosols, Lixisols, Luvisols, Nitisols, Phaeozems, Planosols, Podzols, Regosols, Solochanks, Solonetz and Vertisols. The extent of these units vary in different regions of the country. The fertility and productivity of these soil units also vary. The dominant soil units in the major maize producing areas of Zambia are the Acrisols, Arenosols, Ferralsols and Lixisols. However, Acrisols and Ferralsols cover much of the high rainfall region of Zambia, which is dominated by highly weathered and strongly leached, acidic infertile soils.

The characteristics of the dominant soils of the main maize producing region of Zambia are similar to the soils described by Grant (1981), as the highly leached soils of humid and sub-humid zones in Africa. Most of them are sandy and sandy loam soils that have inherently low nutrient levels, low levels of organic matter and very low cation exchange capacities. These soils are reported to be widespread in Zimbabwe, Zambia and western and southern Mozambique. Deficiencies of nitrogen are reported to be widespread in these soils, while deficiencies of phosphorus, sulfur, magnesium and zinc are also common.



Source: Compiled by Soil Survey Unit, Mount Makulu Central Research Station

Figure 1. Soil map of Zambia, showing major soil units of the FAO Soil Legend

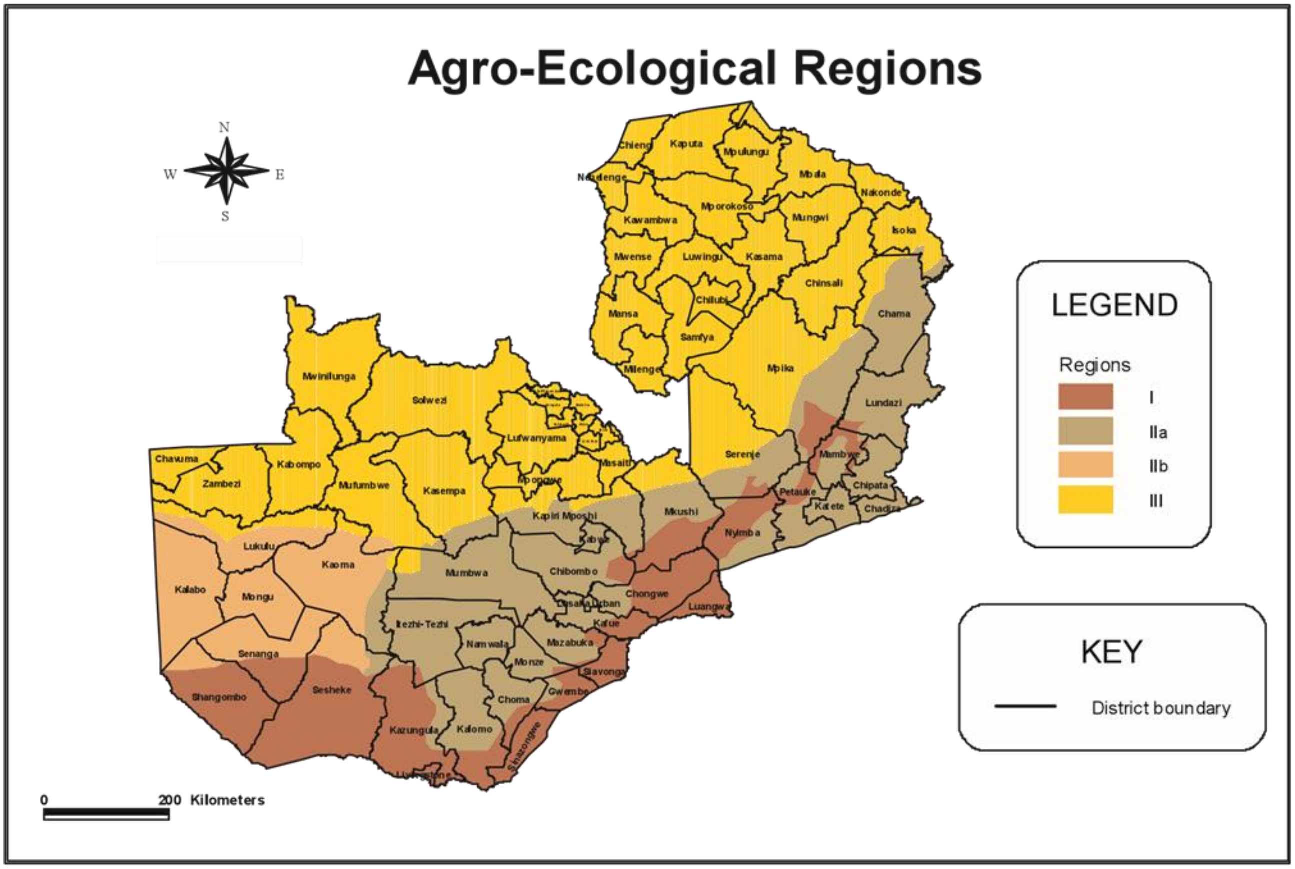
Acrisols are the main agricultural soils in the high rainfall region of Zambia, which is referred to as Agro-ecological region III on the Agro-ecological zone map of Zambia in Figure 2. They are the dominant soils of Luapula, Northern, Muchinga, Copperbelt and parts of North Western Provinces of Zambia. Acrisols also occur in parts of Agro-ecological Region II. They are highly leached acidic soils that have low nutrient and water holding capacities. These soils are often associated with problems of aluminum toxicity, if not limed. Acrisols are generally unsuitable for maize production, but can be used to grow maize with fertilizer application and regular liming.

Arenosols, are the dominant soils in the Western Province and in parts of the North-western Province. These are acidic very infertile sandy soils with little or no profile development. They are derived from the Kalahari sand deposits and typically have pH values of less than 4.0. Arenosols have very low nutrient reserves and nutrient retention capacities and very low water holding capacities. Because of these properties, these soils have very low agricultural potential. However, with careful liming, fertilizer application and addition of organic amendments, the soils can support maize production. The Ferralsols are very highly weathered soils, generally less fertile than Acrisols. They are usually strongly acidic and often exhibit deficiencies of phosphorus and toxicity of aluminum. Ferralsols are most common in the North Western Province.

Lixisols are highly weathered and moderately leached soils but with a base saturation of more than 50 %. They have better nutrient reserves and retention capacities than the soils described in the foregoing paragraphs. These soils are much more fertile and more suitable for maize production. Lixisols are more common in the medium rainfall region of Zambia or Agro-ecological Region II, which is the main maize production region of the country.

2.3.2 Agro-ecological Regions of Zambia.

As earlier discussed, small scale farmers in Zambia, contribute more than 60 % to the total maize production in the country. They depend on rainfall to supply the water required for crop production. For this reason, the annual production of maize is very dependent on the amount and distribution of rainfall in a given season. Zambia is divided into three major agro-ecological regions, namely I, II and III, which are primarily based on rainfall, soil conditions and other climatic factors such as air temperature. Figure 2 shows the main agro-ecological zones of Zambia according to the Soils Research Unit (2006).



Source: Compiled by Soil Survey Unit, Mount Makulu Central Research Station

Figure 2. Agro-ecological Regions Map of Zambia

Agro-ecological Region I, also referred to as the low rainfall region, receives less than 800 mm of annual rainfall. It covers parts of the Southern, Eastern, Central and Western Provinces. Because of the low rainfall, agro-ecological region I is not very suitable for rain fed maize production.

Agro-ecological Region II, or the medium rainfall region, has an annual rainfall between 800-1000 mm. It covers much of the central region of the country, extending from Western Province, through Central Province to parts of Eastern and Muchinga Provinces. Region II is the major maize producing region of Zambia.

Agro ecological Region III or the high rainfall region has an average annual rainfall of 1,000 to 1,500 mm. It covers Northern, Luapula, Muchinga, and Copper belt Provinces. It also covers most of North Western Province and parts of Central Province. Because most of the soils in this region are highly leached, acidic and generally infertile, it is marginally suitable for maize production for farmers with limited access to inputs such as fertilizer and agricultural lime. However, commercial production of maize in this region is possible with adequate investment in inputs such as fertilizer and agricultural lime to overcome the inherent low fertility status of the soils. The rainfall in this region is usually always adequate for maize production.

2.3.3 Status of Fertilizers Use

Sustainable maize production in Zambia is not feasible without application of fertilizers to the soil. Most agricultural soils of Zambia have been reported to be deficient in N and P, while a number of soils are also reported to be deficient in K. Results of a study by Lungu *et al.* (2010) of the nutrient status of 124 soil samples from cultivated fields in 3 districts of the Southern Province of Zambia showed that all or 100 % were deficient in N, 83 % deficient in P and 14 % deficient in K. In a similar study conducted on 288 soil samples collected from agricultural sites in 9 Districts of the Eastern Province of Zambia, Shitumbanuma and Chikuta (2013) reported occurrences of deficiencies of N in 90 % of the samples, P in 39 % of the samples and K in 9 % of the samples. In another study on 162 soil samples from farmers' fields in 9 districts of Zambia, across the three agro-ecological zones, Shitumbanuma *et al.* (2015) reported deficiencies of N in 98 % of the samples, P in 60 % of the samples and K in 43 % of the samples. From the above information it is clear that fertilizers are necessary for maize production in Zambia.

According to, the International Food Policy Research Institute (IFPRI) (1993), about 90 percent of fertilizers used in Zambia are used on maize production. In addition Xu *et al.* (2009), reports that improving maize productivity has been the major goal of the Zambian government's agricultural policy. To achieve this, the government has focused on providing fertilizer subsidies and targeted credit programs to stimulate small scale farmers' crop productivity, with emphasis on maize.

The Agriculture Extension Service under the Ministry of Agriculture recommends the fertilizer application rates of 200 kg/ha Compound D (10 % N, 20 % P_2O_5, 10 % K_2O) as basal dressing and 200 kg/ha Urea (46 % N) as top dressing for maize production by small scale farmers. This recommendation corresponds to an application rate of 112 kg N/ha, 17.5 kg P/ha and 16.5 kg K/ha.

This blanket recommendation may not meet the requirements of some nutrients on soils with very low levels of nutrients. It may also result in the excessive supply of some nutrients in soils with inherently high levels of nutrients. As pointed out by Buresh (2010), the use of blanket fertilizer recommendations for cereals consisting of predetermined rates of N, P, and K for vast areas, assumes that the needs of the crop are constant over time and over large areas. These assumptions are usually not valid.

It is known that the nutrient requirements of a crop can vary greatly across fields, seasons, and years as a result of differences in crop-growing conditions, crop and soil management practices, and the climate. A rational management of nutrients for crops requires an acknowledgement that, nutrient requirements of crops depends on many factors, among which is the inherent fertility of the soil.

2.4 Nutritional and Climatic Requirements for Maize Production

Maize like any other crop requires optimum nutritional and climatic conditions to attain its potential yield. In accordance with Liebig's principle, the most limiting nutrient or environmental requirement determines the actual yield of the crop in a given environment. It is therefore important that the crop is supplied with the right nutrients in adequate amounts and other growth limiting factors.

The yield of maize can be expressed either as the dry matter yield (DMY) which represents the total dry matter accumulation of a crop or as the grain yield (GY). For farmers whose main interest is the grain, the grain is the yield of interest. For those interested in fodder, the DMY is of economic interest. There is a relationship between the DMY and the GY and this is the Harvest Index (HI) represented by formula 1. For grain maize the Harvest Index (HI) is the ratio of the GY to the above ground DMY. It is usually expressed as a percentage.

$$HI = \frac{GY}{DMY} * 100 \qquad (1)$$

For most cultivars, the HI is usually narrow, indicating that the proportion of photosynthetic materials partitioned to the grain does not vary widely. It is therefore possible to predict maize GY from maize DMY. According to Ion *et al.* 2015 the harvest indices of maize range between 30 and 50 %. Stoskopf (1981) reports harvest indices for maize ranging from 40 and 50 %.

2.4.1 Nutritional Requirements for Maize

Maize requires adequate amounts of all nutrients to produce high amounts of grain and dry matter yields. Maize has relatively high nutrient requirements with regard to the primary nutrients N, P and K.

2.4.1.1 Macronutrients

The key macronutrients required in large quantities by maize are N, P and K. According to Yayock *et al.* (1988) the fertilizer requirements for maize grown in tropical conditions are about 100 -120 kg N /ha, 40 kg P/ha and 50 kg K/ha. The FAO and IFA (2000) report nutrient requirements for maize to be 72 – 120 kg N/ha, 16 - 22 kg P/ha and 45 -100 kg K/ha for targeted maize grain yields of 3000 to 6000 kg/ha. Landon (1991) reports maize nutrient requirements of 100 -200 kg N/ha, 50 - 80 kg P/ha and 60 -100 kg K/ha. Besides N, P and K, maize also requires adequate amounts of the macronutrients calcium, magnesium and Sulphur.

Nitrogen (N)

According to Belfield and Brown (2008), N is one nutrient that most often limits maize grain yield. Nitrogen increases vegetative growth and the photosynthetic capacity of the plant and also determines the number of leaves that plants produce and the number of seeds per cob. About two-thirds of the N absorbed by plants end up in the seed at maturity. Nitrogen therefore determines the yield potential of the crop. Nitrogen limits crop production over large areas of Zambia and the main sources of plant-available N are mineralization of soil organic matter (SOM), biological N_2 fixation and fertilizers (Giller *et al.*1997).

Phosphorus (P)

According to Mengel and Kirkby (2001) maize belongs to the group of crops which have high growth rates, produce large quantities of biomass and in turn require large amounts of P. The amounts of P required by crops are usually less than that of N. However most of the P is required during the early stages of crop development to ensure good root growth and to boost shoot and leaf growth. Okalebo and Probert (1992) and Sahoo and Panda (2001) recorded that on soils with low levels of P there is a strong correlation between the maize grain and biomass yields and the amount of P applied to the soil. For this reason the application of P fertilizer on soils with low levels of P is recommended for good maize yields.

Potassium (K)

Potassium plays a key role in the growth and metabolism of plants (Ruiz and Romero, 2002). It is also reported to be essential for efficient N utilization and is said to have a fairly consistent effect on lowering tissue concentrations of calcium and magnesium (Terman *et al.* 1975). Most of the K taken up by maize plants is used in the leaf and stem. The peak period of demand for K is during stem elongation when K uptake is faster than for any other nutrient. As a result significant quantities of K are found in the stover and removed from the field when the whole crop is removed. Potassium is one of the primary nutrient which affects the yield and quality of grain and fruits. According to Mullins and Burmester (1998) the amount K removed from the field by a crop depends upon the plant part that is removed from the field at harvest. For example, more K is removed from a field where forage crops or sugar cane was grown compared to crops where only the grain is removed, because most of above ground biomass is removed from the field when forage crops and sugar cane are harvested, while in grain and fiber crops where only the seed or fiber are harvested, much less K is removed from the field. Supplies of calcium, magnesium and sulphur are equally important to maintain maize yields.

2.4.1.2 Micronutrients

According to Brady and Weil (2002), out of the 16 elements required by plants, there are 7 that have been classified as micronutrients. These are required by plants in relatively small amounts. They include boron (B), copper (Cu), iron (Fe), manganese (Mn), Zinc (Zn), molybdenum (Mo) and Chlorine (Cl). Micronutrients play an active role in plant metabolism processes starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity, nitrogen fixation and reduction. Micronutrient requirements of maize are relatively small. The ranges between the deficiency and toxicity levels in plants and soils are usually narrow.

2.4.1.3 Soil pH

Soil pH is a measure of the relative acidity or alkalinity of the soil solution. The availability of nutrients in the soil is affected by the pH value of the soil. Most crops have an optimal pH range within which they grow well. According to the Cornell Cooperative Extension Service (2005) the recommended pH range for normal growth of maize is 5.8 to 6.2. Landon (1991) cites the optimum pH range to for maize to be 5.5 – 6.0 and a tolerance range for satisfactory yield of 5.0 -8.0.

As soils become acidic nutrients such as P become less available to plants, while elements, such as aluminum, which is not a nutrient, become more available and may reach toxic levels for plants, resulting in reduced crop yields. Liming acid soils, reduces the levels of aluminum in the soil, and increases the availability of most nutrients. When soils become alkaline the availability of micronutrients such as iron, zinc and boron reduces and may limit crop yields. It is therefore essential to maintain the pH of the soils within the optimum range for the crop of interest.

2.4.2 Climatic Requirements

Maize requires optimal climatic conditions for good grain and dry matter yields. Key among the climatic factors required for optimal maize yields are, adequate water or rainfall and favorable temperatures.

2.4.2.1 Water

The water requirements of crops are largely determined by the climatic conditions of the area in which they are grown. Areas with high temperatures and low humidity have much higher water requirements than areas with low temperatures and high humidity. According to Du Plessis (2003), in South Africa, about 10 to 16 kg of grain are produced for every milliliter of water used. Based on the above requirements, a yield of 3 152 kg of maize grain /ha requires between 350 and 450 mm of rain in South Africa. According to Landon (1991) the ideal water requirement for maize growing is between 500 and 800 mm. It should be noted that the water requirements vary with geographic location. Warm to hot environments have higher water requirements than cool to cold environments.

A report by the Japan Association for International Collaboration of Agriculture and Forestry (JAICAF) (2008), indicated that maize production in Zambia experiences substantial annual fluctuations in production associated with the seasonal rainfall. Because of the reliance on rainfall for maize production by small scale farmers in Zambia, maize production is more reliable in areas that have more dependable rainfall. Unfortunately such areas with high rainfall are dominated by soils with inherently low fertility.

According to Belfield and Brown (2008) maize is most sensitive to water stress at the time of tasseling. This is because water is required to facilitate pollination which results in the formation of kernels or grains (Gardner *et al.*1990). After the formation of kernels, water facilitates grain filling which determines the grain weight and final grain yield of the crop. Under rain fed conditions, the water required by the crop is supplied by seasonal rainfall and the water stored in the root zone of the soil. For this reason, deep loamy soils and soils with high organic matter which are able to store much plant available water are considered the most suitable for maize production.

2.4.2.2 Temperature

According to Du Plessis (2003), maize is a warm weather crop, which grows well in areas with mean daily temperatures of less than 19 ºC or where the mean temperature of the summer months is less than 23 ºC. The minimum temperature for maize germination is 10 ºC, and the upper critical temperature likely to detrimentally affect crop yield to be approximately 32ºC. Frost can damage maize plants at all stages of growth and that a frost-free period of 120 to 140 days during the crop growing season is required to prevent frost damage. According to Dalmago *et al.* (2004), increases in the soil temperature reduces the period of germination and emergence of seedlings and increases the rate of growth and activity of plant roots. Warm conditions are therefore favorable for maize growth.

2.4.2.3 Solar Radiation

According to Birch (1997), maize is grown globally from 50°N to 40°S, and from sea level up to 4000 m altitude. Maize is a short-day plant with 12.5 hours/day being suggested as the critical photoperiod. Photoperiods greater than this may increase the total number of leaves produced prior to initiation of tasseling, and may increase the time taken from emergence to tassel initiation. Of all the environmental factors, solar radiation is the second most important to water availability for maize production. It is the source of energy used by plants for photosynthesis. In the tropics the amount of solar radiation received is greatest in semi-arid regions during the dry season just prior to the start of the rain season.

2.5 Maize Production Using Di – Ammonium Phosphate (DAP) Fertilizer

According to Morris *et al.* (2007), the use of fertilizers in many countries is very low, with an average of 8 kg per hectare per year for sub-Saharan Africa. The application of fertilizer on degraded soils without following recommendations has resulted in low crop yields with most countries obtaining maize grain yields of less than 1 metric tonne per hectare as compared to average yields of up to 5 tonnes per hectare obtained with good management. Therefore, the use of fertilizer, in combination with other soil management practices, is necessary to combat adverse effects of poor soil fertility on crop yields.

Research results on the nutrient composition of agricultural soils in Zambia have shown that most soils in Agro-ecological zones I and II contain adequate levels of K for maize production. In areas with such soils it may be prudent to encourage farmers to use basal dressing fertilizers that do not contain K but instead contain higher levels of limiting N and P which are often deficient. In such circumstances DAP may be a suitable substitute to the traditionally used N, P, K containing basal dressing fertilizers such as Compound D.

According to Sutherland *et al.* (1989) DAP is the most widely used phosphate fertilizer. It usually contains 18 % N and 46 % P_2O_5. Di-ammonium phosphate is highly soluble fertilizer which readily releases plant available P and ammonium nitrogen (NH_4 – N). Compared to Compound D (10:20: 10) fertilizer, DAP contains 80 % more N and 140 % more P. It therefore is a potentially good substitute to Compound D on soils that have adequate to high levels of K for maize production.

According to Brady (1984), most mineral soils, other than sandy soils usually have high levels of total K. Research results on the nutrient status of Zambian soils, (Lungu *et al.* (2010), Shitumbanuma and Chikuta (2013) and Shitumbanuma *et al.* (2015)) have shown that the frequency of K deficiency is not as high as that of N and P in most Zambian soils. In soils not lacking K, DAP could be a potential substitute for Compound D fertilizer for maize production. In soils with high levels of K it is therefore prudent to limit the application of K through fertilizers as the additions only lead to luxury consumption without any increase in crop yield.

According to Skowrońska and Filipek (2010), excessive application of K fertilizers leads to luxury consumption of K and has the potential of inducing nutrient imbalances in the crop especially with nutrients such as nitrogen and phosphorus. Douglas *et.al* (2007), caution the use of DAP and Urea, because they have the potential of causing injury to plants if applied at high rates or placed too close to plants. Both DAP and Urea react in the soil to produce free ammonia (NH_3), which can harm germinating seeds and seedlings by burning the plant tissues and inhibiting root growth. The two fertilizers, can however, be used safely in or as starter fertilizers if applied at low rates or if placed appropriately.

2.6 Current Usage of DAP in African Countries

Di- ammonium phosphate fertilizer is widely used in Africa. According to Onyango *et al.* (2000) and Mwangi *et al.* (1997) DAP is the most commonly used fertilizer in areas of Kenya where N and P have been identified to be deficient. Makoka *et al.* (2001), report that in Kaimbu district of Kenya the majority (90.5 %) of farmers that grew maize, preferred using DAP as a basal dressing fertilizer while only about 4.8 % preferred using NPK fertilizers as starter or basal dressing fertilizers.

On the other hand, in some African countries, such as Zambia and Zimbabwe, most farmers use N P K fertilizers even on soils where little or no crop response to additions of K fertilizer was realized. According to Mutezo (2013), despite the fact that there is rarely yield response of maize to the application of K on soils derived from granite in Zimbabwe but the recommended starter or basal Compound fertilizer for maize production in Zimbabwe contains K in addition to N and P. Mutezo (2013) recommended the use of N fertilizer alone after planting or the use of DAP and other P fertilizers as better options of managing the fertility of the K rich soils used for maize production in Zimbabwe. Fufa and Hassan (2006) report that DAP and urea are the two most extensively used and widely promoted fertilizers by the extension service in Ethiopia.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Location of Study Sites

The study was conducted at four locations in agro ecological region II of Zambia. The study sites were in Kabangwe area in Chibombo District, Lwimba area of Chongwe District, Lusaka West area of Chilanga District and Mwachilele area of Rufunsa District. Table 1 shows the geographical coordinates of the four study sites and the classification of the dominant soil types in each location as indicated on the 1:1,000 000 Exploratory Soil Map of Zambia (Ministry of Agriculture, 1991).

Table 1 Geographic coordinates of study sites and major soil units at each site

					Soil Classification	
Study Site	Area	Latitude	Longitude	Soil unit	FAO	USDA
Chibombo	Kabangwe	S15^{o}17'20"	E28^{o}14'50"	Pd5	Lixisol	Alfisol
Rufunsa	Mwachilele	S15^{o}25'53"	E28^{o}56'39"	Pu7	Acrisol	Ultisol
Chilanga	Lusaka West	S15^{o}26'48"	E28^{o}11'37"	Pu25	Phaeozem	Mollisol
Chongwe	Lwimba	S15^{o}31'07"	E28^{o}49'17"	Pd5	Lixisol	Alfisol

The study involved two distinct phases, namely, a greenhouse pot experiment carried out at the School of Agricultural Sciences of the University of Zambia, in Lusaka and on-farm field crop trials conducted at the four locations mentioned above in the 2014/2015 farming season.

3.2 Climate

The climate in Zambia is described as being a moderately tropical continental climate characterized by three distinct seasons. The three seasons are; (i) a cool and dry season from April to August (ii) a hot and dry season from September to October and (iii) a warm wet season from November to March. Most parts of Zambia including Lusaka receives a unimodal rainfall. The four study sites were all in the vicinity of Lusaka City, which is located in agro-ecological region II of Zambia. Lusaka, like much of Zambia receives a unimodal rainfall. The 43 year long term average seasonal rainfall for Lusaka City Airport, the nearest meteorological Station to the four sites with long term climatic data is 812 mm. The 2014/2015 farming season in the field received the lowest seasonal rainfall in 43 years from 1973 to 2016 of 400.5 mm. This rainfall amount was 1.8 standard deviations below the long term average, qualifying the season to have received below normal rainfall from a climatological point of view. Figure 3 shows a comparison of the monthly rainfall distribution in 2014/15 with the 43 year long term means for the different months. The below normal rainfall received in the growing season adversely affected maize growth and yields at the four research sites.

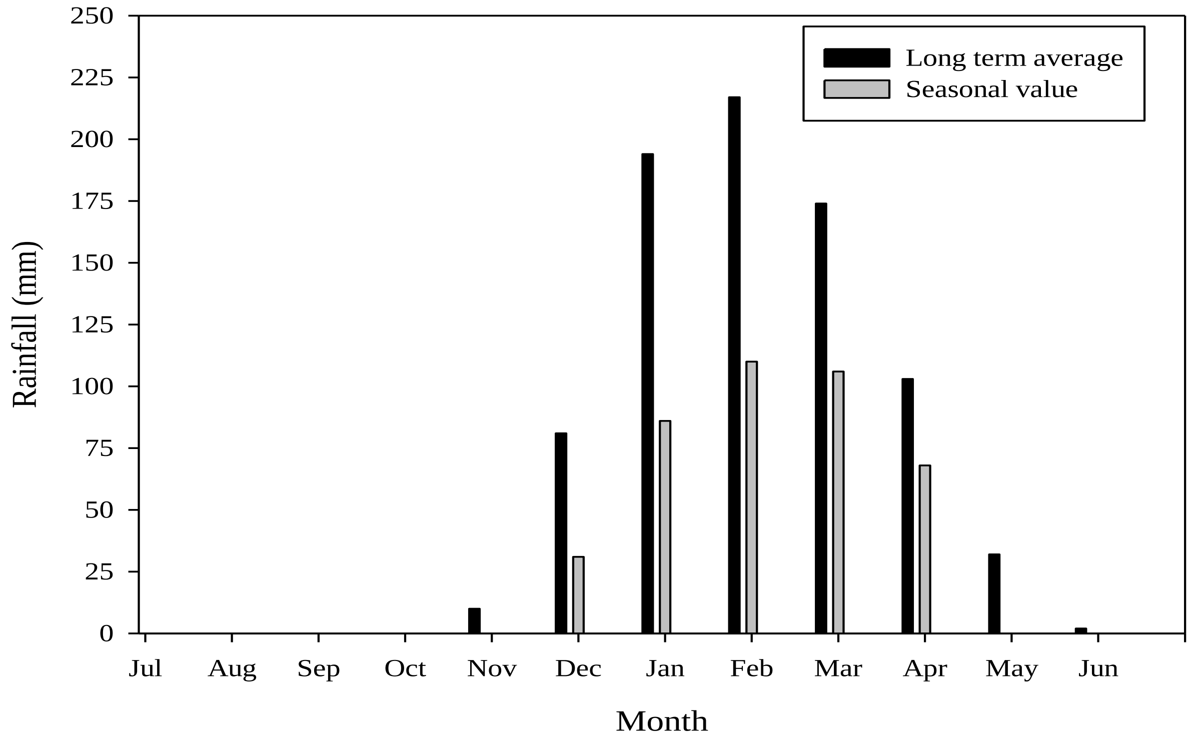


Figure 3. Comparison of rainfall in 2014/2015 season with long term monthly averages

3.3 Site Selection Criteria

The selection of the sites used in the study were based on the accessibility of the sites for purposes of conducting the field operations timely. The sites also had to be fields belonging to small scale farmers who had not used any soil amendments but had been using Compound D fertilizer as a basal dressing fertilizer for maize production. The sites also needed to have low levels of P for maize production. Lastly the sites had to be in locations known to be important maize growing areas in agro-ecological region II, which normally receives adequate rainfall for maize production.

3.4 Soil Sampling

The soils used for the greenhouse studies were collected from surface horizons of fields from the four mentioned sites. A simple random sampling method was used to collect the soil samples. Samples were collected from the top 20 cm of the soil. At each site the field was divided into 4 equal quadrants and samples were collected in each quadrant. The collected samples from each quadrant of a particular site were then thoroughly mixed to make a composite sample. A total of about 100 kg of soil was then collected from each composite sample per site and put in sacks that were clearly labelled for use in both laboratory analyses and for greenhouse pot experiments. Soil samples meant for laboratory analysis were air dried, crushed and passed through a 2 mm sieve. The portion of soil passing through the 2 mm sieve was retained for further analysis.

3.5 Soil Characterisation

Air-dried soil samples that had passed through a 2 mm sieve or the fine earth fraction were used for routine analyses of selected physical and chemical properties. The properties tested on the fine earth fraction included the pH, soil organic carbon, available phosphorus, exchangeable potassium, calcium and magnesium, and the particle size distribution. The methods used to determine the above listed properties are described below.

3.5.1 Determination of pH

The pH of the soil samples was determined in a soil to solution ratio of 1:2.5 in 0.01M $CaCl_2$ according to McLean (1982). Ten grams of the air dried soils was placed in 100 mL conical flasks to which 25 mL of 0.01 M $CaCl_2$ was added. The suspension was then shaken for 30 minutes and allowed to settle for one hour after which the pH was measured using a digital pH meter model PHM82 STANDARD.

3.5.2 Determination of Soil Organic Carbon

The organic carbon content of the soil samples was determined by the Walkley and Black Wet digestion method as described by Nelson and Sommers (1982)**.** One gram of soil was placed in conical flasks to which 10 mL of 1N $K_2Cr_2O_7$ (Potassium Dichromate) was added. Twenty millilitres of concentrated sulphuric acid was later added to the suspension in the conical flasks and left to stand for 30 minutes. One hundred fifty cubic centimetres of distilled water and 10 cm^3 of concentrated phosphoric acid (H_3PO_4) were added to the suspension. Ten drops of

Diphenylamine indicator was then added to the suspension and then the suspension was titrated using Iron (II) Sulphate to give a green colour indicating the end point of the reaction.

A blank was prepared alongside the sample that consisted of all the reagents used in the soil samples except soil itself. The blank was also titrated with the solution of ferrous sulphate. The organic carbon was calculated from the titration volume of the $FeSO_4$ used in the samples and the blank using the formula 2.

$$\%\ \text{Organic carbon} = \frac{\frac{4}{3} * N\left(\frac{eq}{L}\right) * (Vb - Vs)L * \frac{3g\ C}{eq} * 100}{\text{Mass of soil (g)}} \qquad (2)$$

Where: N is normality of $FeSO_4$

Vb is amount of $FeSO_4$ used for blank titration

Vs is volume of $FeSO_4$ used for sample titration

$\frac{4}{3}$ is equivalent of Cr^{6+} reduced per C^{4+} oxidized in the reaction.

From the percentage of organic carbon determined in the sample, the organic matter content of the soil was calculated by multiplying organic carbon by 2 as given in formula 3.

$$\%OM = \%\ \text{Organic Carbon x } 2 \qquad (3)$$

3.5.3 Determination of Particle Size Distribution

To determine the particle size distribution of the soils Buoyoucos hydrometer method (1962) was used. A mass of fifty grams of each soil sample was placed in a dispersing cup to which 50 mL of dispersing agent $Na_6(PO_3)_6$ sodium hexametaphosphate (Calgon) solution was added. The dispersion cup was then half filled with distilled water and the suspension was then stirred using an electric stirrer for 5 minutes. The suspension was then transferred to a 1 litre sedimentation cylinder. A blank was also prepared using the dispersing fluid and distilled water only.

The temperature of the suspension was measured and a plunger was used to agitate the suspension. The hydrometer was carefully lowered into the suspension after 20 seconds and the reading taken at 40 seconds. The hydrometer reading after 40 seconds was used to calculate the amount of silt and clay present in the sample, the result of which was used to determine the percentage of sand in the sample.

The reading was repeated after 2 hours and 8 hours for both the samples and the blank. The hydrometer reading after 2 hours was used to calculate the percentage of clay in the soil sample. The percentages of sand, silt and clay obtained from the analysis of the particle size distribution were then plotted on the USDA Textural Triangle to determine the textural class of the soils.

3.5.4 Determination of Plant Available Phosphorus

To extract the plant available P, the Bray-1 extraction method was used as described by Olsen and Sommer (1982). Three grams of soil was weighed into a 50 mL plastic bottle, to which 21 mL of Bray-1 extracting solution (0.03M NH_4F in 0.25M HCl) was added. The suspension was shaken for one minute on a mechanical shaker and then filtered.

Five millilitres of the filtrate was then transferred to a conical flask to which 4 ml of reagent B which consisted of a freshly prepared ascorbic acid mixed with 12 g ammonium molybdate $(NH_4)_6Mo_7O_{24}$ dissolved in 250 mL distilled water and 1000 mL of 2.5 M H_2SO_4, was added. The mixture was shaken and left to allow the molybdenum blue colour to develop. The concentration of P in the solution was determined by reading the absorbance at 882 nm using a UV-Visible JENWAY 6305 Spectrophotometer. The readings were taken after the instrument was calibrated using standards with concentrations of 0 and 1 ppm P. To calculate the concentration of P in the extract the formula 4 was used:

$$\text{Pconc P}\left(\frac{\text{mg}}{\text{L}}\right) = \frac{\text{Absorbance of sample}}{\left(\dfrac{\text{Absorbance of standard}}{\left(\frac{\text{mgP}}{\text{L}}\right)}\right)} \qquad (4)$$

From the concentrations of P in the extract, the amount of plant available P in the soil was calculated using the formula 5

$$Plant\ avaiable\ P\left(\frac{\text{mg}}{\text{kg soil}}\right) = \frac{\text{Pconc}\left(\frac{\text{mg}}{\text{L}}\right) * \text{ DF} * \text{Vol of extract (L)}}{\text{mass of soil (kg)}} \qquad (5)$$

3.5.5 Determination of Available Potassium

To determine the available K content of the soils, samples were extracted using 1N Ammonium Acetate (NH_4OAc) buffered at pH 7. Twenty five mL of 1N NH_4OAc was added to 5 grams of the soil sample. The suspension was shaken for 30 minutes and then filtered. The concentrations of K in the filtrate were determined on an Atomic Absorption spectrophotometer using the flame emission mode. Concentrations of K obtained from the spectrophotometer were used to determine the amounts of available K in the soil samples using formula 6 below:

$$\frac{\text{K cmol}(+)}{\text{kg soil}} = \frac{\text{Conc K}(\frac{\text{mg}}{\text{L}}) * \text{ DF} * \text{Vol extract (L)} * \frac{10^{-3}\text{g}}{\text{kg soil}} * \frac{\text{cmol}}{\text{cmol wt (mg)}}}{\text{Mass of soil (g)}} \tag{6}$$

3.5.6 Determination of Exchangeable Calcium and Magnesium

To determine the levels of exchangeable Ca and Mg the filtrate obtained during the extraction of K was used. Five millilitres of the filtrate and 5 mL of 5000 mg/L $SrCl_2$ (Strontium Chloride) solution was added in a 25 mL conical flask after which distilled water was added up to the mark. The flasks were filled to the 25 mL mark with 1N NH_4OAc and concentrations of Ca and Mg in the solution were read by Atomic Absorption Spectroscopy (AAS) on a Perkin Elmer Analyst 400 Spectrophotometer. The concentrations of the cations read on the spectrophotometer were used to calculate amounts of exchangeable Ca and Mg in the samples using formulas 7 and 8 below:

$$\text{Ca}\left(\frac{\text{cmol}}{\text{kg Soil}}\right) = \frac{\text{conc Ca}\left(\frac{\text{mg}}{\text{L}}\right) * \text{DF} * \text{Vol extract (L)} * \left(\frac{\text{cmol Ca}}{\text{200mg Ca}}\right) * (\frac{\text{1000g}}{\text{kg soil}})}{\text{Mass of soil (g)}} \tag{7}$$

$$\text{Mg}\left(\frac{\text{cmol}}{\text{kg soil}}\right) = \frac{\text{conc Mg}\left(\frac{\text{mg}}{\text{L}}\right) * \text{DF} * \text{Vol Extract (L)} * \left(\frac{\text{cmol Mg}}{\text{120mg Mg}}\right) * (\frac{\text{1000g}}{\text{kg}})}{\text{g soil}} \tag{8}$$

3.6 Experimental Design and Treatments

3.6.1 Green House Pot Experiment

The first phase of the study was conducted in the greenhouse as a pot experiment laid out as Completely Randomised Design (CRD) with 8 treatments replicated 3 times on 4 soils, giving a total of 96 pots. The treatments used in the experiment are summarized in Table 2.

Table 2.Fertilizer treatments used in the pot study

Treatment ID	Field Fertilizer application rate (kg/ha)	Greenhouse Fertilizer rate (g/pot)	Nutrient levels (kg/ha)		
			N	P_2O_5	K_2O
1	0	0	0	0	0
2	25 DAP	0.56	4.5	12	0
3	50 DAP	1.13	9.0	24	0
4	75 DAP	1.69	13.5	36	0
5	100 DAP	2.25	18.0	48	0
6	125 DAP	2.81	22.5	60	0
7	150 DAP	3.38	27.0	72	0
8	200 Comp D	4.5	20.0	40	20

The required rates of fertilizer per pot were weighed on a balance in the laboratory in triplicate for each treatment and each soil. The fertilizer was then mixed with 3 kilograms of soil in plastic dishes. The soils mixed with the different rates of fertilizer were then placed in 2.85 litre polyethylene pots into which four (4) seeds of the maize variety MRI 514 were planted on 28th November, 2014. On 22nd December, 2014, one week after emergence, the maize plants were thinned to one healthy plant per pot as shown in Figure 4.

The pots were watered regularly and weeded by hand as required until the maize plants were six weeks old of vegetative growth. The pot trials were not top dressed and on 2nd January, 2015, six weeks after planting, the above ground portion of the maize plants were harvested, cut into small pieces, placed in labelled paper bags and left to air dry in the greenhouse for two weeks as shown in Figure 5. On 22nd February, 2015 the air dried maize plants were weighed and the weights were recorded. The dry mass of the plants was taken as the above ground dry matter yields (DMY) of the maize plants at six weeks.

Figure 4. Maize plants in the Green house after thinning

Figure 5. Air drying of above ground maize dry matter in brown paper bags in green house.

3.6.2 On-Farm Field Crop Trials

The second phase of the study was conducted as on-farm field trials at the four sites from which soils used in the greenhouse trials were collected. These field crop trials were conducted during the 2014/2015 agricultural or farming season.

3.6.2.1 Set Up and Management of Field Crop Trials

At each study site, 20 x 20 m plots were secured for the trials. The plots were formerly cultivated fields that had the same history of usage. The field experiments were laid out as Complete Randomised Design (CRD), with 8 treatments and 4 replications and 8 treatments randomly assigned to each plot within each block. Table 3 gives a description of the basal fertilizer rates in the 8 treatments.

Table 3. Basal fertilizer application rates for the 8 treatments used in the field crop trials

Treatment ID	Field Fertilizer application rate per hectare (kg/ha)	Nutrient levels (kg/ha)		
		N	P_2O_5	K_2O
1	0	0	0	0
2	50 DAP	9.0	24	0
3	75 DAP	13.5	36	0
4	100 DAP	18.0	48	0
5	125 DAP	22.5	60	0
6	150 DAP	27.0	72	0
7	200 DAP	36.0	96	0
8	200 Comp D	20.0	40	20

Each block was 4.5 m wide, and had inter block spacing of 0.5 m. The blocks represented replicates that were divided into eight 2.5 m wide plots for each treatment. Planting basins were dug manually at each field with intra-row spacing of 0.75 m and an inter-row spacing of 0.5 m as shown in Figure 6.

Figure 6. Digging planting basins at Rufunsa Field Trial site in Rufunsa District

Each plot within the block had five (5) rows and five (5) planting stations per row, giving 25 planting stations per plot and a total of 800 planting stations per site. Fertilizer rates per planting station per treatment were calculated and corresponding amounts were weighed in the laboratory. The fertilizers used as starter or basal dressing were Compound D (10 % N: 20 % P_2O_5:10% K_2O) and DAP (18 % N: 46 % P_2O_5: 0 % K_2O). Fertilizer treatments were randomly assigned to each plot within a block.

Before planting, the basal dressing fertilizer was placed in the planting basins, and covered with soil to prevent direct contact between the seed and fertilizer as stipulated by Verma *et al.* (2012). The test crop used in the study was an early maturing maize variety, MRI 514 that takes 125 days to mature. It is said to be best suited for the low rainfall areas of agro-ecological regions I and II, and has a potential yield of 10 tonnes/ha. It is reported to be resistant to common maize pests and diseases.

Five seeds of the maize variety MRI 514 were then placed in each planting basin and covered with soil. Just after planting, the weed killer glyphosate was sprayed to kill weeds present in the plots (Figure 7). Three weeks after emergence, the planting stations at all the sites were thinned leaving three healthy plants per station. No serious weed infestation occurred up to the time of harvest following the initial application of the herbicide at the time of planting.

Figure 7. Spraying the herbicide glyphosate on weeds after planting at Chibombo site

Urea was applied as a top dressing fertilizer to all treatment plots except the control 7 weeks after planting at a rate corresponding to 200 kg/ha or 92 kg N/ha. The actual dates of planting and top dressing at the different sites are presented in Table 4.

Table 4 Dates of planting and top dressing at the different on-farm crop trial sites

Site	Planting Date	Date of Top dressing application
Chibombo	31st December, 2014	24th February, 2015
Rufunsa	7th January, 2015	23rd February, 2015
Chilanga	10th January, 2015	21st February, 2015
Chongwe	11th January, 2015	25th February, 2015

Crops at all field trials sites were harvested in June of 2015. The cobs were left to dry until August when they were weighed. Ten randomly selected cobs from each plot were weighed and the grain from these cobs were also weighed. The total mass of all grains obtained from each plot were also weighed. The dry grain mass was used to calculate the corresponding grain yield per hectare using formula 9 below.

$$Maize\ Grain\ Yield\ \left(\frac{kg}{ha}\right) = \frac{Maize\ Grain\ Yield\ (g) per\ plot}{Area\ (Plot) m^2} * \frac{1kg}{1000g} \tag{9}$$

The data of the maize dry matter yield from the greenhouse pot experiment and the maize grain yield from the field crop trials were then used to calculate the Relative Agronomic Effectiveness (RAE) for different DAP fertilizer rates, relative to the yields from plots or pots with 200 kg/ha Compound D as indicated in formula 10.

$$RAE\ (\%) = \left(\frac{Yield\ of\ Treat - Yield\ of\ Control}{Yield\ Reference - Yield\ of\ Control}\right) * 100 \tag{10}$$

where: *Yield of Treat*: maize yield on plots/pots with a specific fertilizer rate

Yield of Reference: maize yield for plots/pots with 200kg/ha Compound D

Yield of Control: maize yield on plots/pots without fertilizer

3.7 Statistical Analysis of the Pot Experiment and the Crop Field Trials

To determine whether there were significant differences in maize dry matter yields among the various treatments used in the pot experiment and in the grain yields of maize from the field crop trials, an Analysis of Variance (ANOVA) was conducted. To separate treatment means when results of the ANOVA indicated significant differences between treatment effects, Duncan's Multiple Range Test (DMRT) was employed. The critical levels of significance used for all statistical tests was at 0.05. All the statistical analysis was conducted using the SAS software version 9.1.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Soil Characterization

The characteristics of the four soils used in the study are given in Table 5 below.

Table 5. Selected properties of soils used in the study

Parameter	Chibombo	Chongwe	Chilanga	Rufunsa
Soil pH (0.01M $CaCl_2$)	4.73	5.54	6.14	4.92
Soil Organic Matter (%)	2.23	2.30	3.46	4.15
Soil Texture	Sandy Loam	Silt Loam	Loam	Sandy Clay Loam
Available P (mg/kg soil)	6.20	2.14	5.32	1.89
Available K(cmol(+).kg $soil^{-1}$)	0.13	0.50	0.89	0.50
Ca (cmol(+).kg $soil^{-1}$)	6.68	3.35	1.14	3.28
Mg (cmol(+).kg $soil^{-1}$)	2.76	1.31	0.62	3.05

The pH of the four soils ranged from 4.73 to 6.14. The Phaeozems at Chilanga were neutral, the Lixisols at Chongwe were moderately acid, while Lixisols at Chibombo and Acrisols at Rufunsa were both strongly acid. According to Landon (1991) the optimum pH range for maize is 5.5 – 6.0 while the tolerance range for satisfactory yield is 5.0 to 8.0. The Cornell Cooperative Extension Service (2005) cites a pH range of 5.8 to 6.2 as the recommended range for normal growth of maize.

The pH values of Lixisols at Chongwe and Phaeozems at Chilanga were within the recommended range for maize production, while the Lixisols at Chibombo and Acrisols at Rufunsa were below the desirable pH range for maize. According to Brady (1984) when soils are acidic, the population and activity of microorganisms in the soil responsible for transforming nitrogen, sulfur, and phosphorus to plant-available forms usually decline.

Soil organic matter (SOM) contents ranged from 2.23 to 4.15 %. According to Mutsaers *et al.* (1997) SOM contents of 3 % or more are rated as high, those from 2 to 3 % as medium, and those less than 2 % as low. And Donahue (2003) has stated that availability of plant nutrients in soils is greatly affected by soil organic matter. Based on this rating, Acrisols at Rufunsa and Phaeozems at Chilanga had high levels of SOM, while the Lixisols at Chibombo and Chongwe had medium levels of SOM. According to Nieuwenhuis and Schöll (2004), when the pH and SOM are both classified as low, crop yields may decline. This is because of the reduced microbial activity which results in lower decomposition of organic matter and consequently the low release of nutrients.

Soils at the four trial sites all had loamy textures. The soil textures were sandy loams at Chibombo, silt loam at Chongwe, loam at Chilanga and sandy clay loam at Rufunsa. Soil texture plays an important role in plant nutrition due to its effect on water and nutrient retention (Jones and Jacobsen, 2001). According to Brady (1984), loamy soils are the preferred soils for agronomic use. The ideal loam is a mixture of sand, silt and clay particles that exhibits intermediate properties between those of light and heavy soils.

The available P levels in the four soils ranged from 1.89 and to 6.20 mg/kg soil. Mutsaers *et al.* (1997) cite a Bray-1 available P value of 12 mg/kg as the critical value of P for soils in savannah regions for maize production. According to Shitumbanuma *et al*. (2014) research results on Zambian soils indicate that the critical levels of Bray-1 extractable P used to demarcate soils with low P from those with high P for maize production are 12 and 26 mg P/kg soil respectively. Soils with less than 12 mg P/kg soil are responsive to applications of phosphate fertilizers while those with more than 26 mg P/kg soil are not likely to be responsive to applications of phosphate fertilizers. All the soils used in the study had low levels of available P for maize production, and were thus expected to show maize yield responses to applications of P fertilizers.

Levels of available K in the soils used in the study ranged from 0.13 to 0.89 cmol (+) kg soil. According to Menzies *et al.* (2007) the critical value of K for maize production is 0.22 cmol (+) kg/soil. Shitumbanuma *et al*. (2014) reported values of 0.2 and 0.44 to be limits of exchangeable K demarcating soils with low and high levels of K for maize production in Zambia. Based on the above interpretations, the Lixisols at Chibombo had low levels of K while the other three soils had adequate to high levels of K.

According to Menzies *et al.* (2007) the critical values for Ca and Mg in soils are 0.5 to 1.5 cmol/kg soil and 0.2 to 0.3 cmol/kg soil respectively. All the soils had adequate levels of Ca and Mg indicating that Ca and Mg were not likely to limit crop yields on the soils at the study sites.

4.2 Results of Greenhouse Pot Trials

The appearance of maize plants grown on the different soils six weeks after planting are shown in Figures 8 to 11. The pots in Figures 8 to 11 were lined up in a decreasing order of fertilizer application rates from left to right. Pots on the extreme left had an equivalent of 200 kg Compound D/ha, while pots on the far right were the controls or had no fertilizer applied to them. Figure 8 shows maize plants grown on soils from Chongwe, while Figures 9, 10 and 11, show maize plants grown on soils from Chibombo, Rufunsa and Chilanga respectively. The plants on all soils were arranged in order of increasing rates of fertilizer from right to left. It is clear from all the Figures, that there was a general increase in the growth of maize as the rates of DAP fertilizer applied to the pots increased from 0 in the control plots to 150 kg/ha. The observed general increase in maize growth was expected in response to increases in N and P associated with increasing rates of DAP and due to the N, P and K supplied by the Compound D fertilizer in pots on the far left of each Figure.

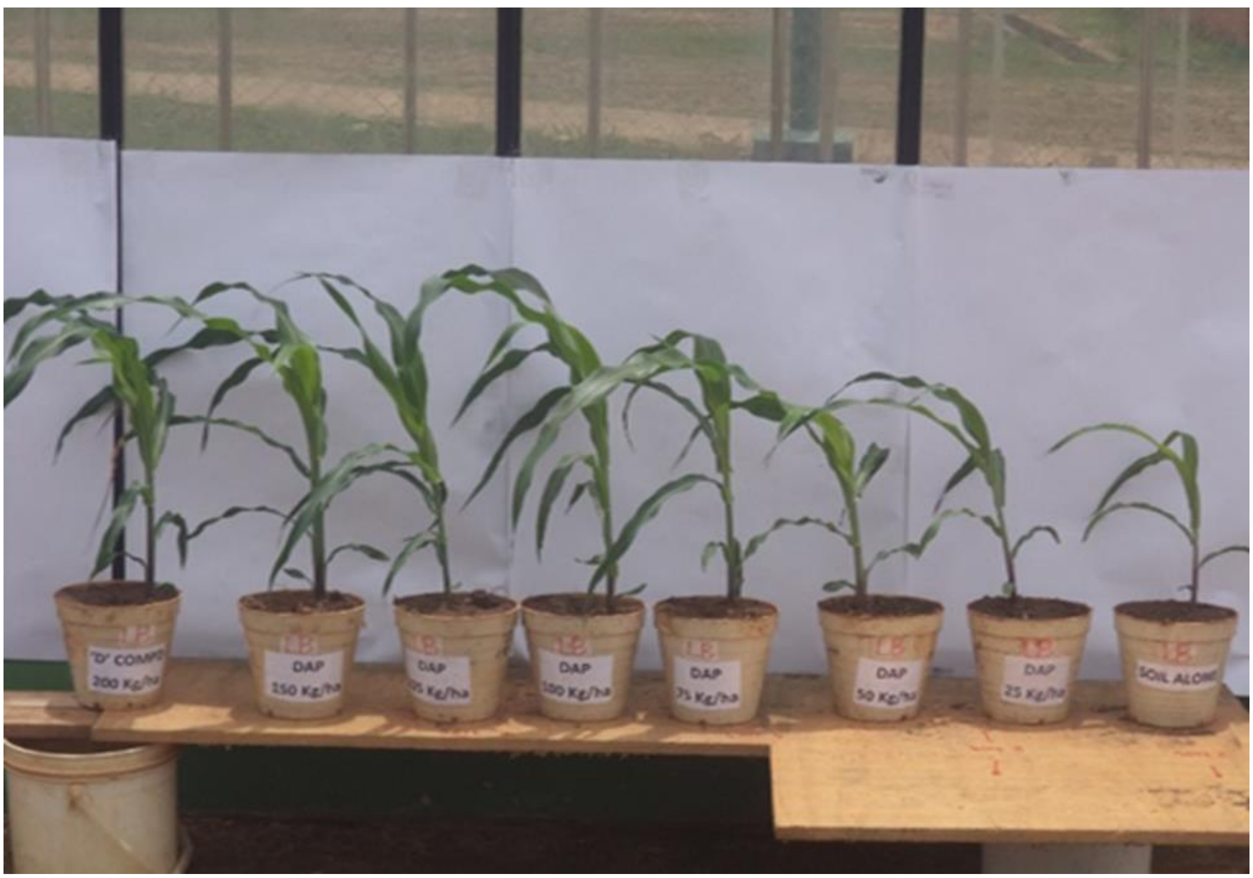


Figure 8. Maize plants on soils from Chongwe 6 weeks after planting

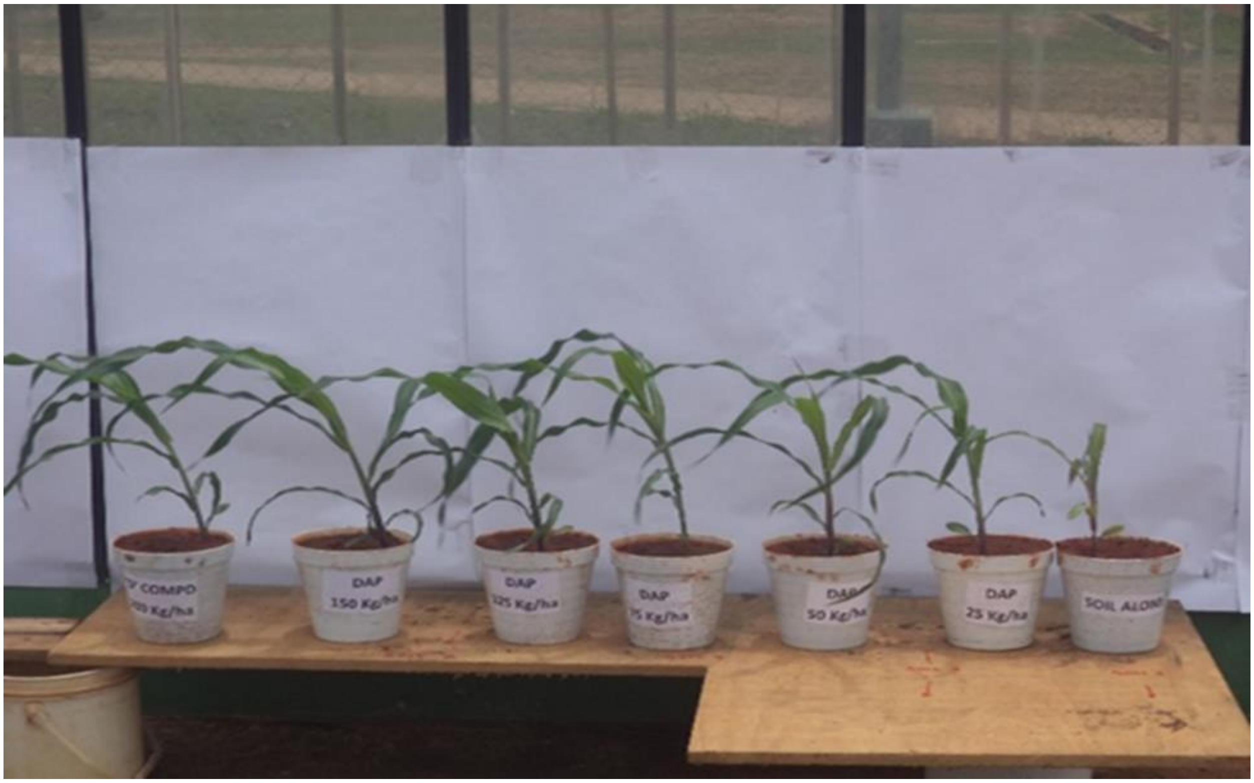


Figure 9. Maize plants on soils from Chibombo 6 weeks after planting

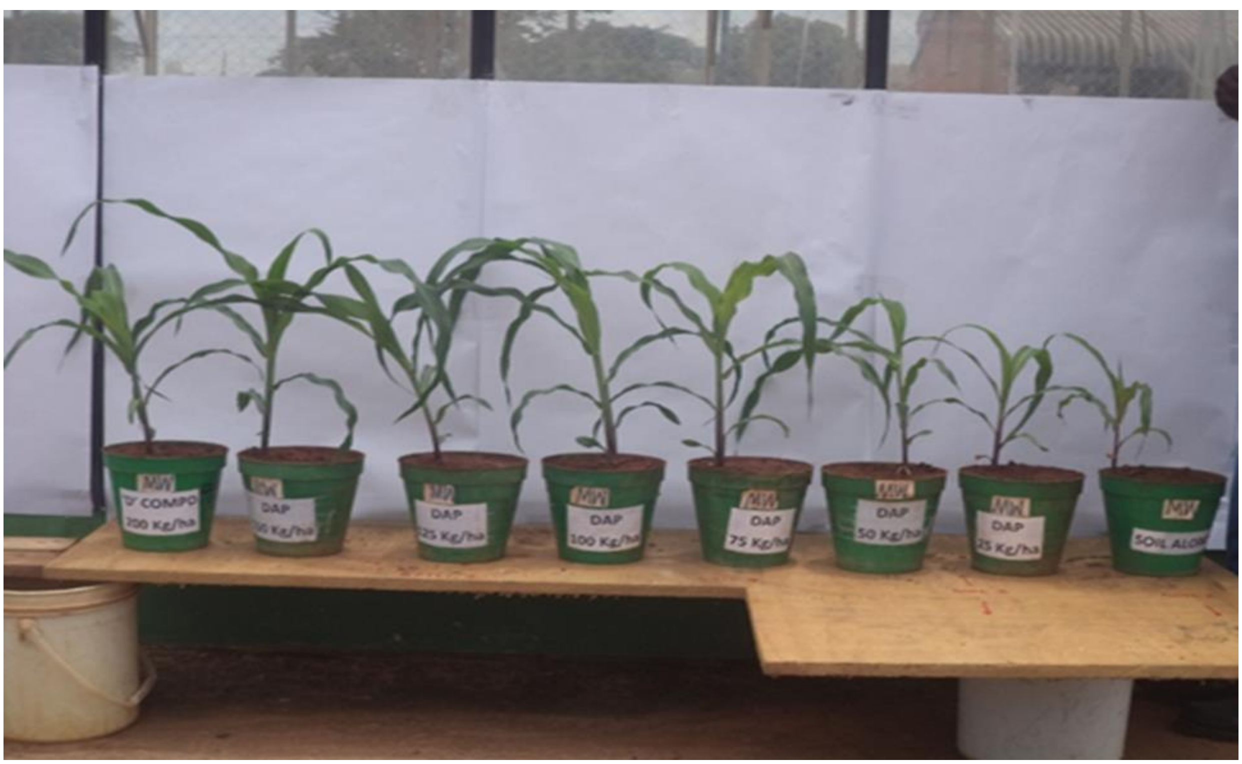


Figure 10. Maize plants on soils from Rufunsa 6 weeks after planting

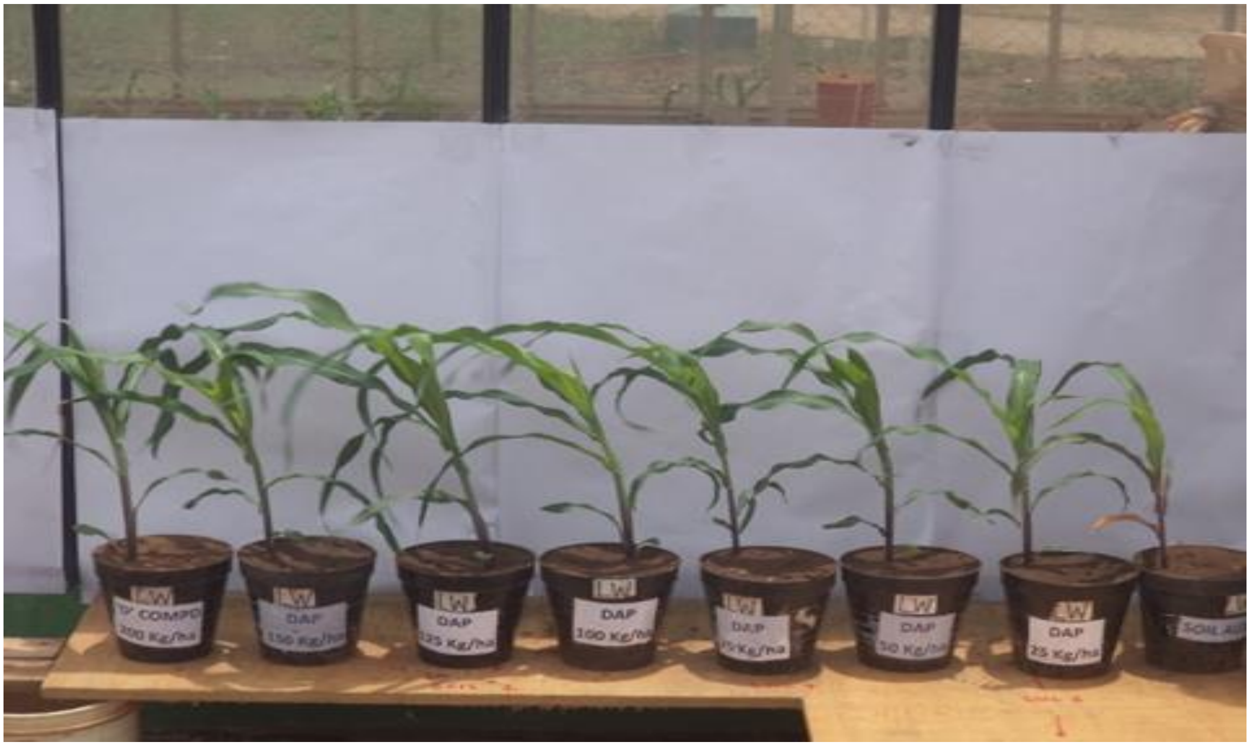


Figure 11. Maize plants on soils from Chilanga 6 weeks after planting

4.2.1 Results of Maize Dry Matter Yield

A summary of the dry matter yield of maize plants from different treatments on the soils used in the study are presented in Table 6. On the soils from Chilanga, Rufunsa and Chongwe that had adequate levels of K, no statistically significant ($p < 0.05$) differences were observed between maize dry matter yields from pots with an equivalent of 100 kg DAP/ha and those from pots with an equivalent of 200 kg Compound D/ha. However, a significant difference was observed between the dry matter yield of maize plants from pots with the 100kg DAP/ha treatment and that of the 200 kg Compound D/ha treatment on the soil from Chibombo. The dry matter yield from the 100 kg DAP/ha treatment on Chibombo soil was significantly lower than that of the 200 kg Compound D/ha treatment.

Results of the dry matter yields were in agreement with what was anticipated, based on the nutrient contents of the soils. On soils that had adequate levels of K, no significant yield increase was expected from applications of K to the soils. As such dry matter yields from treatments with Compound D fertilizer were not expected to be greater than those of DAP containing the same levels of N and P as the rate of Compound D applied. On the other hand, on soils that had low levels of K, higher dry matter yields were expected from the application of Compound D containing the same levels of N and P as 100 kg DAP. The results obtained were in agreement with these predictions, based on the initial nutrient contents of soils.

Table 6: Mean Maize dry matter yields on different soils at 6 weeks after planting

Treatment ID	Fertilizer Treatment (kg/ha)	Maize Dry Matter Yield (g/pot)			
		Chibombo	Chongwe	Chilanga	Rufunsa
1	0 DAP	1.43d	7.74 b	5.46d	1.72e
2	25 DAP	7.48c	13.23b	13.63c	6.27de
3	50 DAP	10.89b	12.62b	14.60c	9.60cd
4	75 DAP	11.76b	21.16a	18.09c	13.88bc
5	100 DAP	13.16b	19.34a	20.65ab	18.13ab
6	125 DAP	12.95b	22.75a	20.02ab	18.28ab
7	150 DAP	12.98b	23.12a	23.64a	22.39a
8	200 Comp D	17.25a	24.34a	18.35abc	13.83bc
	Mean	11.0	18.04	16.80	13.01
	CV (%)	16.28	17.60	18.40	24.22

Mean values within the column followed by the same subscript are not significantly different at 0.05 level of significance using the Duncan Multiple Range Test.

4.2.2 Relative Agronomic Effectiveness (RAE) of DAP based on Maize Dry Matter Yield

Table 7 presents results of RAEs of DAP on different soils used in the study based on the maize dry matter yields obtained from greenhouse pot experiments. On Chongwe, Chilanga and Rufunsa soils which had adequate levels of K for maize production, there were statistically no differences ($p < 0.05$) between the RAE of 100 kg DAP/ha and 100 %, indicating that DAP applied at 100 kg/ha on these soils was as effective as Compound D applied at 200 kg/ha. According to Sime and Aune (2014), the high exchangeable K level in soils indicates that a response to K fertilizer is unlikely for cereals. Hence, for increased grain and biomass yield, yearly application of N and P fertilizer is required and the easiest way to increase soil N and P is the addition of inorganic nutrients, such as urea and di-ammonium phosphate (DAP). However, on the soil from Chibombo, the RAE of 100 kg DAP/ha was significantly lower than 100 %, indicating that RAE of 100 kg DAP/ha was less than that of 200 kg Compound D/ha.

Table 7. Mean RAE for different treatments on soils in the Green House Pot Experiment

Treatment ID	Fertilizer Application Rate (kg/ha)	RAE (%)			
		Chibombo	Chongwe	Chilanga	Rufunsa
1	0 DAP	0	0	0	0
2	25 DAP	38.2c	33.1b	63.4c	37.6de
3	50 DAP	59.8b	29.9b	70.9c	65.1dc
4	75 DAP	65.3b	80.9a	98.0c	100.4bc
5	100 DAP	74.1b	69.9a	117.8ba	135.5ba
6	125 DAP	72.8b	90.5a	112.9ba	136.8ba
7	150 DAP	73.0b	92.7a	141.1a	170.8a
8	200 Comp D	100a	100a	100bac	100bc
	Mean	60.4	62.04	88.00	93.26
	CV (%)	18.72	30.83	27.26	27.19

Results of the RAEs of DAP on the four soils, are in agreement with results of the soil tests presented in Table 5. Soils that had adequate to high levels of K had RAEs for 100 kg DAP/ha not significantly less than 100 % while the RAE of 100kg DAP/ha for soil with low levels of K was significant less than 100 % as anticipated.

Summary of the RAE of DAP applications based on Maize Dry Matter Yields on all Soils

Figure 12 shows the RAE of increasing rates of DAP on Phaeozems at Chilanga and Acrisols at Rufunsa. These two soils were the most responsive to applications of DAP. On the Acrisols a rate of 75 kg DAP/ha or an equivalent of 34.5 kg P_20_5/ha had a RAE of 100 %, while on the Phaeozems, a rate of 90 kg DAP/ha or an equivalent of 41.5 kg P_2O_5/ha had an RAE of 100 %.

It is clear that on these two soils DAP was an effective source of N and P. Both these soils had high initial levels of SOM and available K. Organic matter is an important source of N, P and S in soils. According to Stevenson (1986), nitrogen, phosphorus and sulfur are mineralized from SOM at a rate of 1 to 3 % of their total contents in SOM in the course of the growing season. Therefore soils with high SOM usually obtain significant amounts of these nutrients from the decomposition of the organic matter.

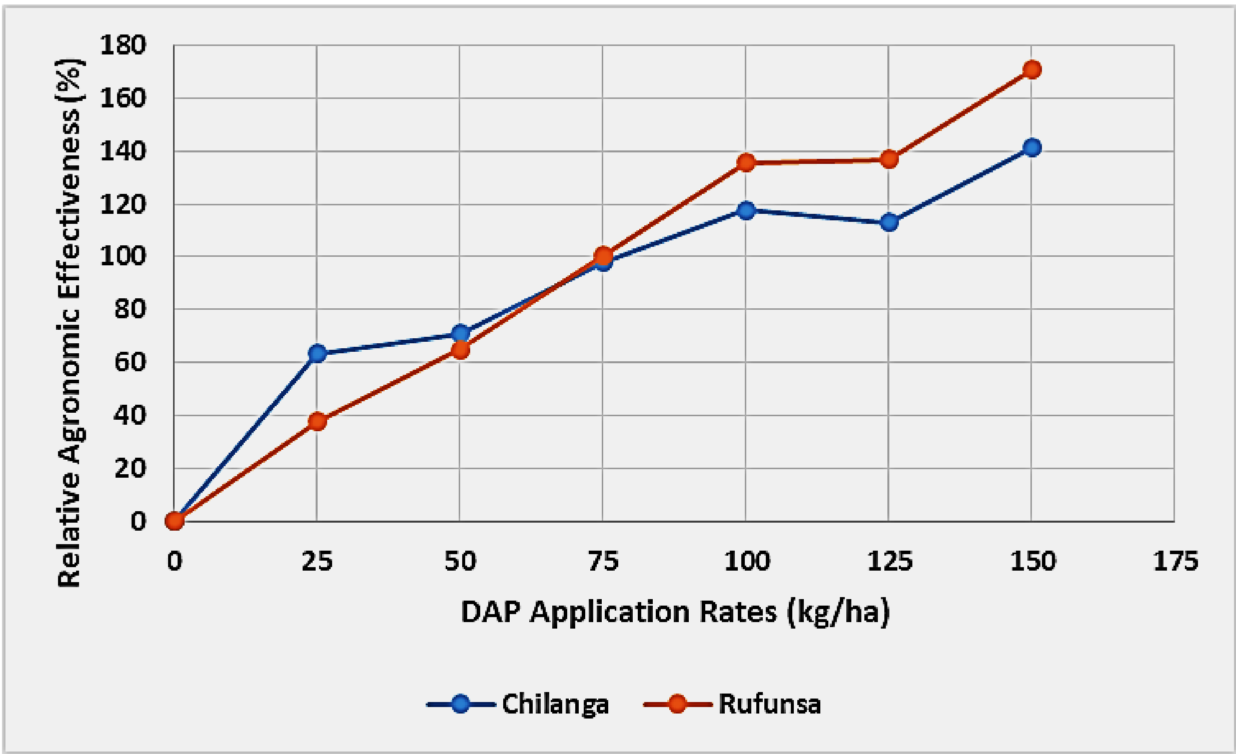


Figure 12. RAE of DAP based dry matter yields on soils from Chilanga and Rufunsa

According to Yayock *et al.* (1988), the fertilizer requirements for maize under tropical conditions is about 100-120 kg N /ha, 40 kg P_2O_5/ha and 50 kg K/ha. The cited rate of P_2O_5 is what is contained in 200 kg Compound D/ha, the recommended basal fertilizer rate for smallholder farmers growing maize in Zambia. It is also quite close to the P_2O_5 content of 100 kg DAP/ha which was used in this study as the rate equivalent to 200 kg D/ha.

The 40 kg P_2O_5/ha can be met by lower rates phosphate chemical fertilizers, on soils with high amounts of SOM because a significant portion of P in such soils comes from organic matter when

SOM is decomposed (Juo and Franzluebbers 2003). On soils with low SOM, higher amounts of phosphate fertilizers are required to supply the stated rate of P.

Figure 13 show the RAE of DAP on the Lixisols from Chongwe and Chibombo. There was an intermediate response to applications of DAP. The mean values of the RAE for 100 kg DAP/ha as shown in Figure 17 on these soils were less than 100 %. The soils at Chongwe had high levels of K and moderate levels of SOM, while those at Chibombo which showed the least response had low levels of K and moderate levels of SOM. It appears that the dry matter yield response of maize to DAP was related to the initial levels of K and SOM in the soils. Soils with high initial levels of K and SOM were more responsive to applications of DAP than soils with low initial levels of K and SOM. In addition, according to Okalebo and Probert (1992) and Sahoo and Panda (2001) soils with low levels of P shared a strong correlation between the maize grain and biomass yields and the amount of P applied to the soil.

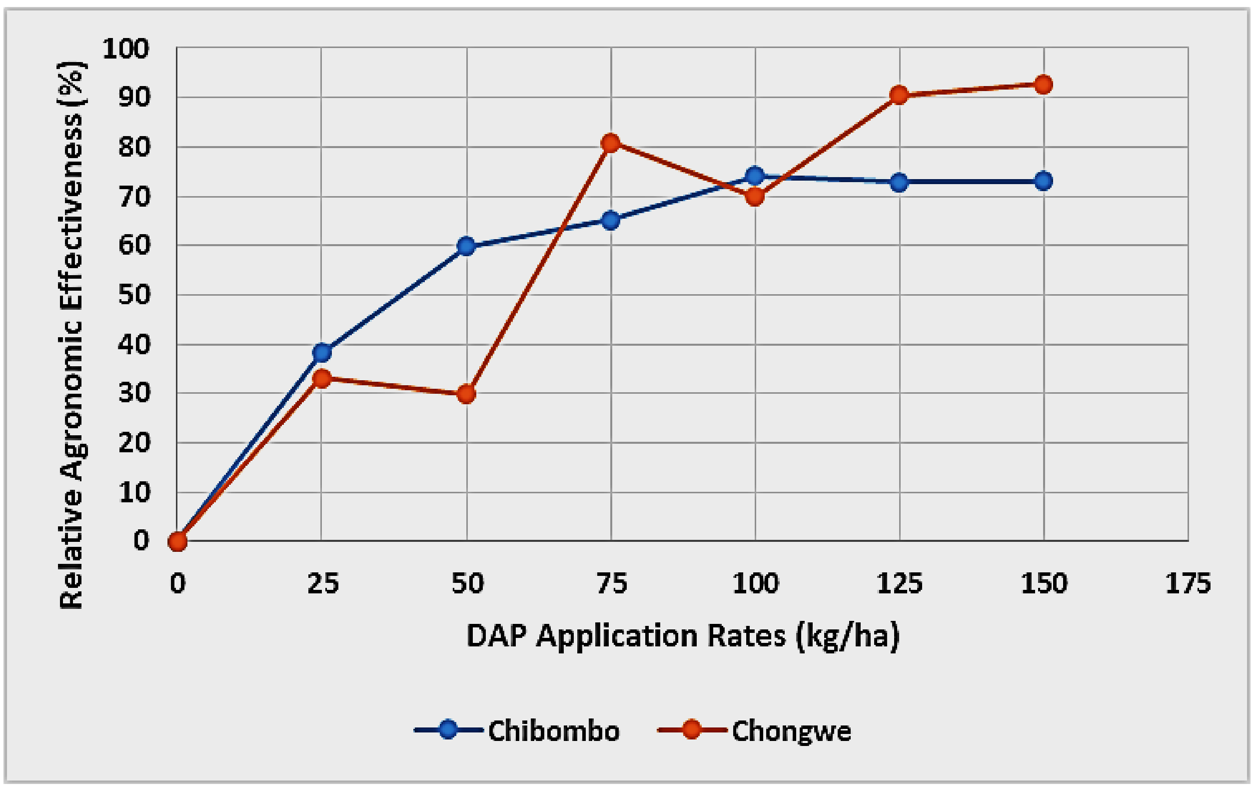


Figure 13. RAE of DAP based on dry matter yields on soils from Chibombo and Chongwe

4.3 Results of Maize Grain Yields

4.3.1 Seasonal rainfall in 2014/15

During the 2014/2015 agricultural season, there was very low rainfall compared to the long term average at the four study sites. As such, grain yields were adversely affected by the low rainfall. Rainfall data from Lusaka City Airport meteorological station which is located centrally among the four sites, showed that the rainfall for the 2014/2015 season was the lowest over a period of 43 years from 1973 to 2016 as shown in Figure 14. The rainfall received in the 2014/2015 season of 400.5 mm was 49 % of the long term average rainfall of 812 mm. The rainfall in this season was lower than normal as discussed in section 3.2. Higher yields with less variability would most likely have been obtained if the rainfall had been normal. Although various rainfall amounts are cited for different locations it should be noted that actual amounts vary between geographical locations. An amount of rainfall that may be adequate for maize in one geographical location may be inadequate in another location. The actual rainfall should be assessed with regard to the average amount for that particular location.

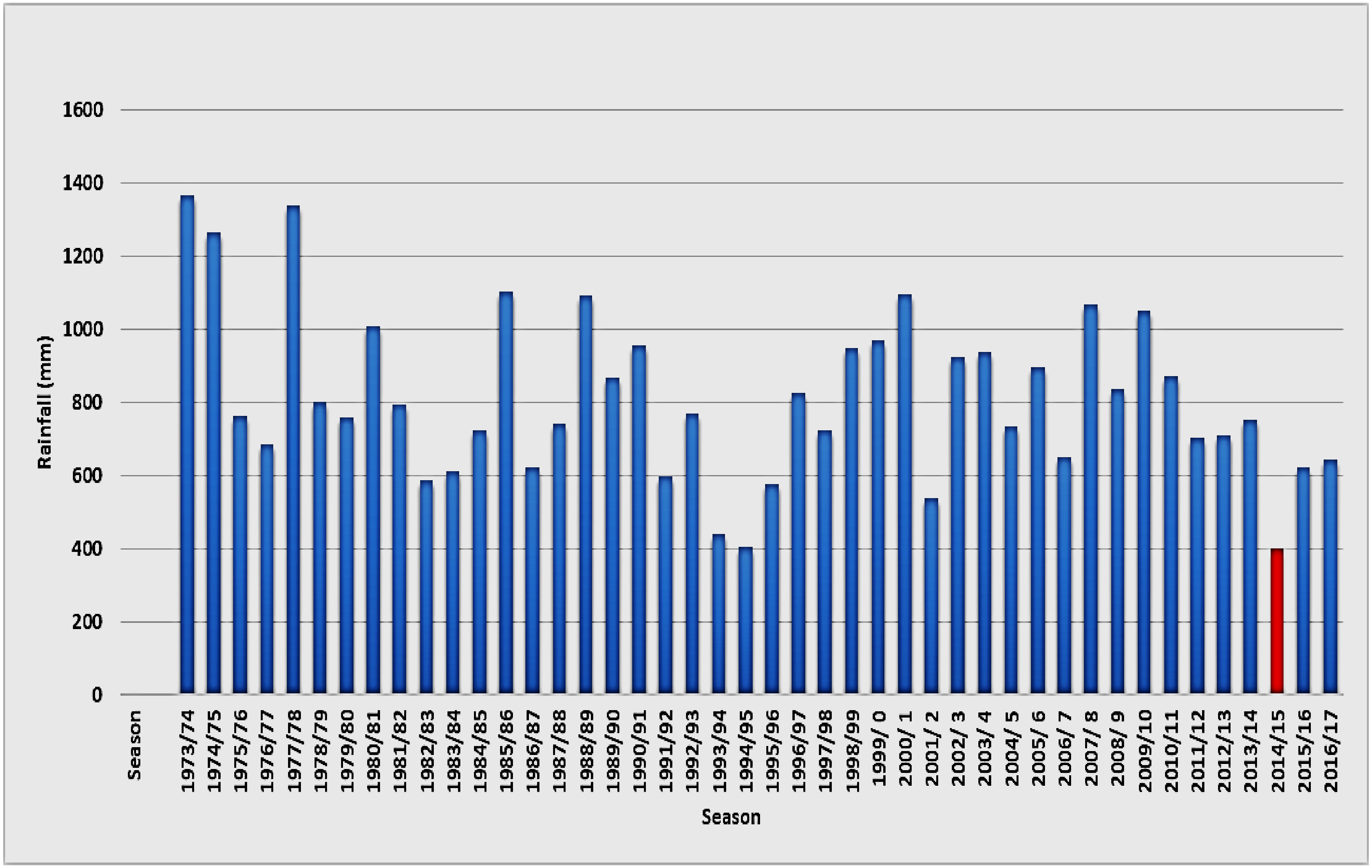


Figure 14. Seasonal rainfall for the period 1973 to 2016 for Lusaka City Airport Station

4.3.2 Maize Grain Yield

Figure 15. Partial layout of the field at Rufunsa site taken on 7 February, 2015

A summary of the mean maize grain yields for different treatments from the four field trial sites is presented in Table 8. No statistically significant differences ($p < 0.05$) were observed between maize grain yields from plots with 100 kg DAP/ha and plots with 200 kg Compound D/ha at all the four trial sites, indicating that DAP at 100 kg/ha was as effective as 200 kg Compound/ha in producing maize grain at all the four sites. The results further imply that under the conditions that prevailed in the 2014/15 season, DAP at 100 kg/ha could have been used as a substitute for 200 kg Compound D.

The response of maize to applications of DAP on soils from Chilanga, Rufunsa and Chongwe, were generally in agreement with results of the greenhouse pot trials. On these soils maize grain yields on plots with 100 kg DAP/ha were not significantly different from those of 200 kg Compound D/ha. However, the maize response to DAP in the field trials at Chibombo was different from that of the pot trials. In the field trials, at Chibombo soils, maize grain yields from plots with 200 kg Compound D/ha were not significantly ($p < 0.05$) higher than those from plots with 100 kg DAP/ha, while in the pot trials, dry matter yields from the 200 kg Compound D treatment were significantly greater than those of the 100 kg DAP/ha treatment.

Table 8. Mean maize grain yields under different treatments on different soils

Treatment ID	Fertiliser Treatment (kg/ha)	Maize Grain Yields (kg/ha)			
		Chibombo	Chongwe	Chilanga	Rufunsa
1	0 DAP	248.53c	1324.40c	2318.53a	252.44a
2	50 DAP	1532.40b	2361.73ab	2596.53a	611.91a
3	75 DAP	1858.53ab	2103.60bc	2934.67a	313.24a
4	100 DAP	1960.93ab	2642.80ab	2918.80a	741.51a
5	125 DAP	2343.87ab	2066.67bc	2764.53a	574.75a
6	150 DAP	1981.73ab	2974.40a	3213.07a	803.55a
7	200 DAP	2662.67a	3221.73a	3091.33a	1232.53a
8	200 Comp D	2558.13ab	3145.20a	2463.60a	552.17a
	Mean	1893.35	2480.07	2787.63	635.27
	CV (%)	33.47	22.02	25.13	108.37

4.3.2 Relative Agronomic Effectiveness of DAP based on Maize Grain Yields

Results of the RAE of DAP at the four study sites based on maize grain yield are presented in Table 9. No statistically significant ($p < 0.05$) difference between the effectiveness of 100 kg DAP/ha and 200 kg Compound D/ha was observed at all four study sites indicating that 100 kg DAP/ha was as effective as or better than 200 kg Compound D/ha in producing maize grain yields. The values of the RAEs for 100 kg DAP/ha agree with general expectations based on results of the soil tests presented in Table 5 for soils at Chongwe, Chilanga and Rufunsa. However, on soils at Chibombo the RAE from the field trials differed with those of the greenhouse pot trials. In the field trials the 100 kg DAP/ha treatment was not less significantly effective as 200 kg Compound D, which is contrary to the results obtained from greenhouse trials, which showed that DAP at 100 kg/ha was less effective than 200 kg Compound/ha.

Table 9. Relative Agronomic Effectiveness (RAE) per Treatment for the Field Crop Trials

Treatment ID	Fertilizer Treatment (kg/ha)	RAE (%)			
		Chibombo	Chongwe	Chilanga	Rufunsa
1	0 DAP	0	0	0	0
2	50 DAP	55.59bc	56.97b	191.6a	119.9a
3	75 DAP	69.71dc	42.80ba	424.7a	20.30a
4	100 DAP	74.14bac	72.41ba	413.8a	163.20a
5	125 DAP	90.72dc	40.77ba	307.40a	107.5a
6	150 DAP	75.04ba	90.62ba	616.6a	183.90a
7	200 DAP	104.52a	104.20a	532.7a	327a
8	200 Comp D	100ba	100a	100a	100a
	Mean	71.21	63.47	323.34	127.71
	CV (%)	38.5	47.2	149.3	179.8

It may not be surprising that results from field trials differed from those obtained from pots trials, because there are notable differences between pot trials and field trials. In the pot trials, the soils used were from the surface horizon, while in the field plant roots grew in the surface and subsurface horizons. The properties of the subsurface horizons were not taken into consideration in the pot trials. Since the field trials, reflect the actual performance of the fertilizer in the field, results from field trials indicate that DAP at 100 kg/ha was as effective as 200 kg Compound D/ha on Chibombo soil.

Summary of the RAE of DAP applications based on Maize Grain Yields on all Sites

Figure 16 shows the relationship of the mean values of the RAE to application rates of DAP based on the maize grain yields on the Phaeozems and Acrisols at Chilanga and Rufunsa. The mean RAE of 100 kg DAP/ha on soils at these two sites was more than 100 %.

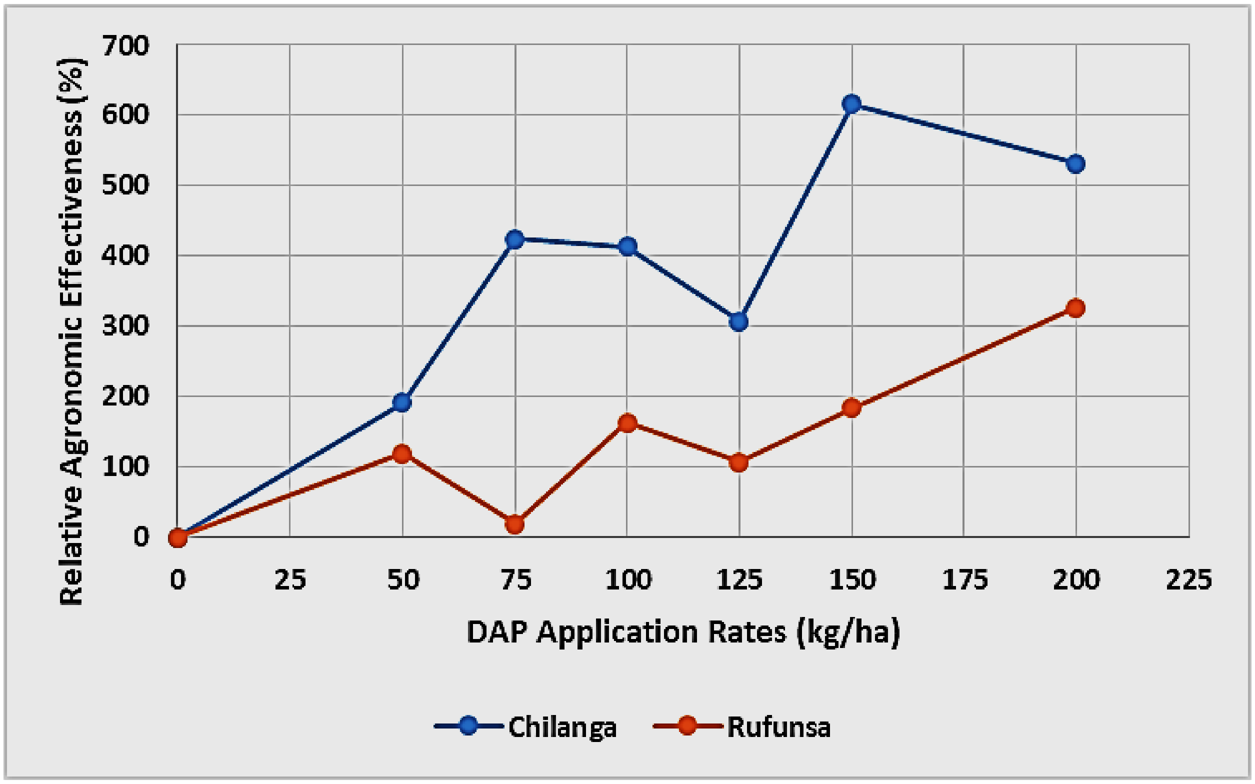


Figure 16. RAE of DAP based on Maize Grain Yields at Chilanga and Rufunsa Sites

As earlier discussed the Phaeozems at Chilanga and Acrisols at Rufunsa had high levels of SOM and K. It is likely that the SOM in these soils supplied significant amounts of N and P to plants and thus reduced the requirements of N and P fertilizers. On these soils 100 kg DAP/ha was more effective than 200 kg Compound D. A number of studies have shown that a rate of 40 kg P_2O_5/ha is about the optimum for growing maize on tropical soils with low P fixation. Ayodele and Akinola, (1982), found a rate of 40 kg P_2O_5/ha to be optimum for maize production in savannah soils of Western Nigeria. Onasanya *et al.* (2009) recommended an application rate of 120 kg N/ha + 40 kg P_2O_5/ha for increasing maize yields in Southern Nigeria. Kogbe and Adediran, (2003), also recommended 100kg N and 40 kg P_2O_5 as the optimum rates of N and P_2O_5 for maize grown on soils in the savannah regions of Nigeria. In India, Hnamte *et al.* (2016) also recommended a rate of 40 kg P_2O_5 as optimum for growing maize. The FAO and IFA (2000) report nutrient requirements for maize to be 72 – 120 kg N/ha, 16 - 22 kg P/ha and 45 -100 kg K/ha for targeted maize grain yields of 3000 to 6000 kg/ha, which is within the same range of P reported by other researchers.

Figure 17 presents the curves of mean values of the RAE of different rates of DAP based on the maize grain yields on the Lixisols at Chongwe and Chibombo. The mean RAEs of 100 kg DAP/ha on soils at these two site were generally lower than 100 % although they were not statistically different from 100 %, indicating that on average lower yields were obtained from plots with 100 kg DAP/ha at these two sites than from plots that received 200 kg Compound D/ha. These two soils as earlier discussed had moderate levels of SOM. As such they had low to moderate natural reserves of N and P, and thus required higher amounts of N and P from chemical fertilizers to attain optimum yields. On these soils higher rates of DAP were thus required to obtain equivalent yields to applications of 200 kg Compound D/ha.

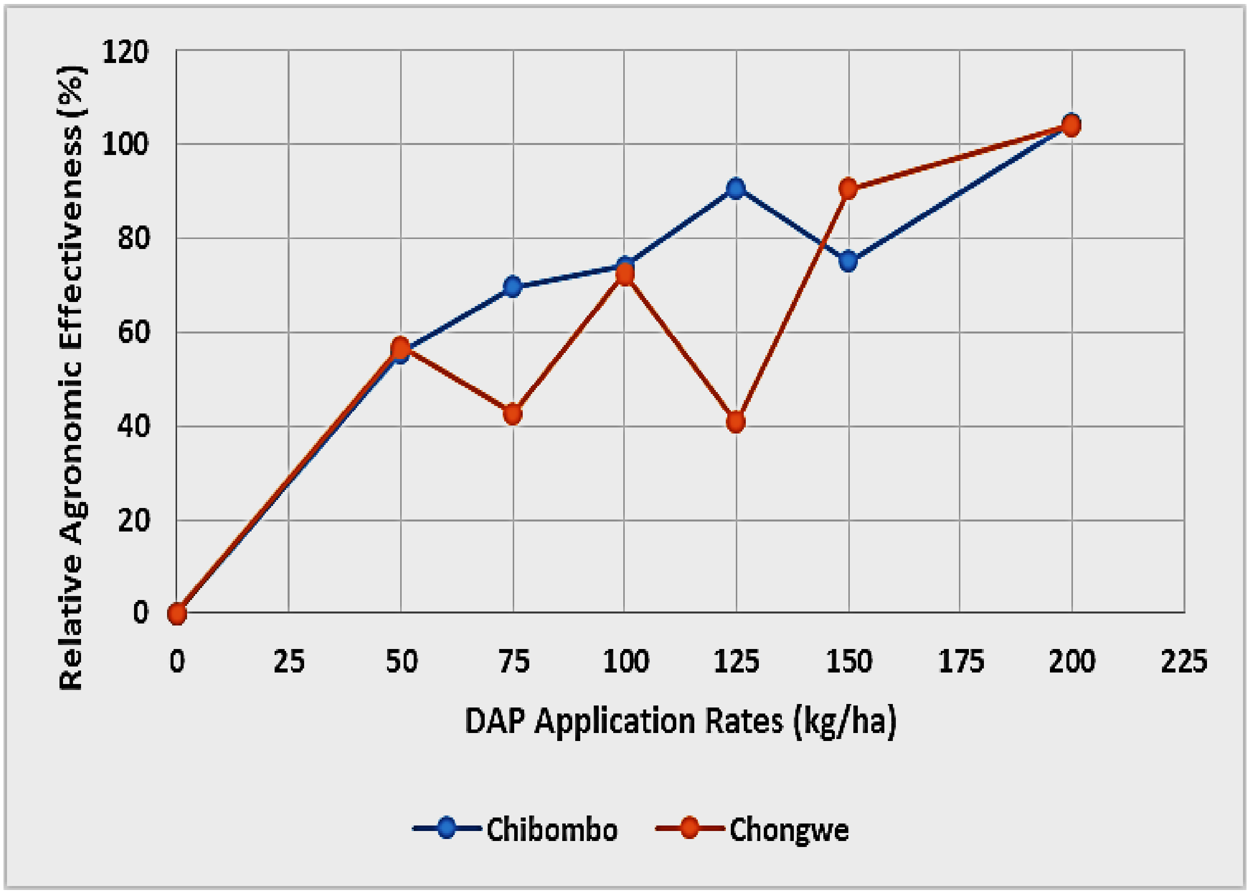


Figure 17. RAE of DAP based on maize grain yields at Chongwe and Chibombo

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results of this study have shown that applying 100 kg DAP/ha was as effective as the application of 200 kg/ha of Compound D in producing vegetative maize dry matter yields on Phaeozems, Acrisols and Lixisols from Chilanga, Rufunsa and Chongwe respectively, but less effective on the low K containing Lixisols from Chibombo. Results of the field crop trials, showed that 100 kg DAP/ha was as effective as 200 kg Compound D/ha on all four soils in producing maize grain yield. The effectiveness of DAP was greater on soils containing high levels of available K and soil organic matter than on soils with moderate to low organic matter. The results have demonstrated that DAP at a rate of 100 kg/ha can be used to substitute 200 kg Compound D/ha for producing maize grain yields on soils with low P but containing moderate to high amounts of K and soil organic matter.

5.2 Recommendations

Based on the results of this study it is recommended that:

1) DAP be considered as a potential alternative basal dressing fertilizer to compound D on soils with low levels of P, having moderate to high levels of K and soil organic matter.

2) Soil testing be encouraged among small holder farmers to help them identify whether or not they need to use Compound D or DAP as their basal dressing fertilizer for maize production.

3) Further field studies to be conducted to establish the suitability of other potential fertilizer as substitutes to Compound D.

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APPENDICES

Appendix 1. Maize dry matter yields for Crop Trials

Obs	Soil	rate	fert	DM
1	LW	0	DPA	5.39
2	LW	0	DPA	3.56
3	LW	0	DPA	7.44
4	LW	25	DPA	14.49
5	LW	25	DPA	15.28
6	LW	25	DPA	11.13
7	LW	50	DPA	17.90
8	LW	50	DPA	13.52
9	LW	50	DPA	12.37
10	LW	75	DPA	18.38
11	LW	75	DPA	13.06
12	LW	75	DPA	22.83
13	LW	100	DPA	17.98
14	LW	100	DPA	21.43
15	LW	100	DPA	22.53
16	LW	125	DPA	19.92
17	LW	125	DPA	20.40
18	LW	125	DPA	19.73
19	LW	150	DPA	25.11
20	LW	150	DPA	20.78
21	LW	150	DPA	25.03
22	LW	200	D	17.81
23	LW	200	D	13.79
24	LW	200	D	23.45
25	LB	0	DPA	6.88
26	LB	0	DPA	7.14
27	LB	0	DPA	9.20
28	LB	25	DPA	13.41
29	LB	25	DPA	9.32
30	LB	25	DPA	16.95
31	LB	50	DPA	7.53
32	LB	50	DPA	16.14
33	LB	50	DPA	14.18
34	LB	75	DPA	22.79
35	LB	75	DPA	20.22
36	LB	75	DPA	20.48
37	LB	100	DPA	21.89
38	LB	100	DPA	13.12
39	LB	100	DPA	23.00
40	LB	125	DPA	25.06
41	LB	125	DPA	21.10
42	LB	125	DPA	22.10
43	LB	150	DPA	21.97
44	LB	150	DPA	21.13
45	LB	150	DPA	26.26
46	LB	200	D	25.42
47	LB	200	D	24.06
48	LB	200	D	23.53
49	GNR	0	DPA	1.28
50	GNR	0	DPA	1.44

Obs	Soil	rate	fert	DM
51	GNR	0	DPA	1.58
52	GNR	25	DPA	9.82
53	GNR	25	DPA	5.36
54	GNR	25	DPA	7.26
55	GNR	50	DPA	8.35
56	GNR	50	DPA	9.37
57	GNR	50	DPA	14.95
58	GNR	75	DPA	11.16
59	GNR	75	DPA	13.01
60	GNR	75	DPA	11.10
61	GNR	100	DPA	12.98
62	GNR	100	DPA	13.43
63	GNR	100	DPA	13.07
64	GNR	125	DPA	14.27
65	GNR	125	DPA	12.26
66	GNR	125	DPA	12.32
67	GNR	150	DPA	12.20
68	GNR	150	DPA	11.43
69	GNR	150	DPA	15.32
70	GNR	200	D	17.92
71	GNR	200	D	16.01
72	GNR	200	D	17.83
73	MW	0	DPA	1.57
74	MW	0	DPA	2.00
75	MW	0	DPA	1.60
76	MW	25	DPA	5.71
77	MW	25	DPA	1.67
78	MW	25	DPA	11.43
79	MW	50	DPA	5.94
80	MW	50	DPA	9.30
81	MW	50	DPA	13.55
82	MW	75	DPA	17.11
83	MW	75	DPA	10.24
84	MW	75	DPA	14.28
85	MW	100	DPA	18.98
86	MW	100	DPA	18.82
87	MW	100	DPA	16.58
88	MW	125	DPA	18.42
89	MW	125	DPA	23.14
90	MW	125	DPA	13.29
91	MW	150	DPA	21.80
92	MW	150	DPA	23.08
93	MW	150	DPA	22.30
94	MW	200	D	12.47
95	MW	200	D	15.51
96	MW	200	D	13.50

Appendix 2. Mean maize dry matter yields and RAE of DAP in greenhouse trials.

Soil	rate	Obs	Variable	Mean	Std Error
GNR	0	3	DM	1.4333333	0.0866667
			RAE	0.0021070	0.5478298
	25	3	DM	7.4800000	1.2921816
			RAE	38.2237674	8.1680254
	50	3	DM	10.8900000	2.0512435
			RAE	59.7787611	12.9661411
	75	3	DM	11.7566667	0.6269060
			RAE	65.2570586	3.9627433
	100	3	DM	13.1600000	0.1374773

			RAE	74.1276865	0.8690093
	125	3	DM	12.9500000	0.6602272
			RAE	72.8002528	4.1733706
	150	3	DM	12.9833333	1.1892902
			RAE	73.0109566	7.5176370
	200	3	DM	17.2533333	0.6222093
			RAE	100.0021070	3.9330552
LB	0	3	DM	7.7400000	0.7338483
			RAE	-3.55271E-15	4.4215720
	25	3	DM	13.2266667	2.2044979
			RAE	33.0581832	13.2825084
	50	3	DM	12.6166667	2.6055091
			RAE	29.3828202	15.6986752
	75	3	DM	21.1633333	0.8167891
			RAE	80.8780703	4.9213057
	100	3	DM	19.3366667	3.1248058
			RAE	69.8720652	18.8275337
	125	3	DM	22.7533333	1.1889117
			RAE	90.4581149	7.1634135
	150	3	DM	23.1200000	1.5886157
			RAE	92.6673495	9.5717042
	200	3	DM	24.3366667	0.5628598
			RAE	99.9979916	3.3913343
LW	0	3	DM	5.4633333	1.1206595
			RAE	0.0025866	8.6960466
	25	3	DM	13.6333333	1.2722727
			RAE	63.3998086	9.8725280
	50	3	DM	14.5966667	1.6846991
			RAE	70.8750420	13.0728573
	75	3	DM	18.0900000	2.8240810
			RAE	97.9824629	21.9141846
	100	3	DM	20.6466667	1.3706244
			RAE	117.8215773	10.6357131
	125	3	DM	20.0166667	0.1993601
			RAE	112.9329298	1.5469860
	150	3	DM	23.6400000	1.4301865
			RAE	141.0491193	11.0979007
	200	3	DM	18.3500000	2.8016424
			RAE	100.0000000	21.7400665
MW	0	3	DM	1.7233333	0.1386042
			RAE	0.0027539	1.1451103
	25	3	DM	6.2700000	2.8313483
			RAE	37.5660939	23.3918401
	50	3	DM	9.5966667	2.2018200
			RAE	65.0501212	18.1908456
	75	3	DM	13.8766667	1.9934253

		RAE	100.4103327	16.4691449
100	3	DM	18.1266667	0.7747114
		RAE	135.5226922	6.4004578
125	3	DM	18.2833333	2.8442710
		RAE	136.8170302	23.4986041
150	3	DM	22.3933333	0.3724394
		RAE	170.7727473	3.0769944

Appendix 3. ANOVA for RAE of DAP on Chibombo Lixisols in greenhouse trials

```
                              The GLM Procedure
                             Class Level Information
                Class         Levels    Values
                rate               8    0 25 50 75 100 125 150 200
                           Number of observations    24
Dependent Variable: RAE
                                      Sum of
       Source                  DF        Squares     Mean Square    F Value    Pr > F
       Model                    7     18699.73943      2671.39135      20.89    <.0001
       Error                   16      2045.98137       127.87384

       Corrected Total         23     20745.72080
                 R-Square     Coeff Var      Root MSE      RAE Mean
                 0.901378      18.72197      11.30813      60.40034
                         Mean values of dry matter yields
```

Appendix 4. Mean Comparisons for RAE of DAP on Chibombo Lixisols in greenhouse trials

```
                                The GLM Procedure
                              t Tests (LSD) for RAE
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.
                         Alpha                             0.05
                         Error Degrees of Freedom            16
                         Error Mean Square             127.8738
                         Critical Value of t            2.11991
                         Least Significant Difference   19.573
                    Means with the same letter are not significantly different.
                         t Grouping          Mean      N    rate
                                 A       100.002      3    200
                                 B        74.128      3    100
                                 B
                                 B        73.011      3    150
                                 B
                                 B        72.800      3    125
                                 B
                                 B        65.257      3    75
                                 B
                                 B        59.779      3    50
                                 C        38.224      3    25

                                 D         0.002      3    0
```

Appendix 5. ANOVA for RAE of DAP on Chongwe Lixisols in greenhouse trials

```
                              The GLM Procedure
                           Class Level Information

              Class         Levels    Values

              rate               8    0 25 50 75 100 125 150 200

                        Number of observations    24


Dependent Variable: RAE
                                          Sum of
       Source                      DF         Squares     Mean Square    F Value    Pr > F

       Model                        7     28074.13726      4010.59104      10.96    <.0001

       Error                       16      5853.31303       365.83206

       Corrected Total             23     33927.45029

                       R-Square     Coeff Var      Root MSE      RAE Mean

                       0.827476      30.83002      19.12674      62.03932
```

Appendix 6. Mean Comparisons for RAE of DAP on Chongwe Lixisols in greenhouse trials

```
                             The GLM Procedure

                           t Tests (LSD) for RAE
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

                        Alpha                             0.05
                        Error Degrees of Freedom            16
                        Error Mean Square             365.8321
                        Critical Value of t            2.11991
                        Least Significant Difference   33.106
                  Means with the same letter are not significantly different.
                      t Grouping          Mean      N    rate

                              A        100.00      3    200
                              A
                              A         92.67      3    150
                              A
                              A         90.46      3    125
                              A
                              A         80.88      3    75
                              A
                              A         69.87      3    100

                              B         33.06      3    25
                              B
                              B         29.38      3    50
                              B
                              B         -0.00      3    0
```

Appendix 7. ANOVA for RAE of DAP on Chilanga Phaeozems in greenhouse trials

The GLM Procedure

Class Level Information

Class	Levels	Values
rate	8	0 25 50 75 100 125 150 200

Number of observations 24

Dependent Variable: RAE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	39632.44185	5661.77741	9.83	<.0001
Error	16	9213.14744	575.82172		
Corrected Total	23	48845.58929			

R-Square	Coeff Var	Root MSE	RAE Mean
0.811382	27.26605	23.99629	88.00794

Appendix 8. Mean Comparisons for RAE of DAP on Chilanga Phaeozems in greenhouse trials

The GLM Procedure

t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	575.8217
Critical Value of t	2.11991
Least Significant Difference	41.535

Means with the same letter are not significantly different.

t Grouping			Mean	N	rate
	A		141.05	3	150
	A				
B	A		117.82	3	100
B	A				
B	A		112.93	3	125
B	A				
B	A	C	100.00	3	200
B		C			
B		C	97.98	3	75
		C			
		C	70.88	3	50
		C			
		C	63.40	3	25
	D		0.00	3	0

Appendix 9. ANOVA for RAE of DAP on Rufunsa Acrisols in greenhouse trials

The GLM Procedure

Class Level Information

Class	Levels	Values
rate	8	0 25 50 75 100 125 150 200

Number of observations 24

Dependent Variable: RAE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	67147.84718	9592.54960	14.15	<.0001
Error	16	10845.80711	677.86294		
Corrected Total	23	77993.65429			

R-Square	Coeff Var	Root MSE	RAE Mean
0.860940	27.91523	26.03580	93.26738

Appendix 10. Mean Comparisons for RAE of DAP on Rufunsa Acrisols in greenhouse trials

The GLM Procedure

t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	677.8629
Critical Value of t	2.11991
Least Significant Difference	45.065

Means with the same letter are not significantly different.

t Grouping		Mean	N	rate
	A	170.77	3	150
	A			
B	A	136.82	3	125
B	A			
B	A	135.52	3	100
B				
B	C	100.41	3	75
B	C			
B	C	100.00	3	200
	C			
D	C	65.05	3	50
D				
D	E	37.57	3	25
	E			
	E	0.00	3	0

Appendix 11. Maize Grain yields for different treatments in the Field Trials

Summary of Yield data from Field Trials

Obs	Soil	Treat	rate	GrainWt (g/plot)	Yield (kg/ha)
1	GNR	0DAP	0	271	240.89
2	GNR	0DAP	0	341	303.11
3	GNR	0DAP	0	431	383.11
4	GNR	0DAP	0	821	729.78
5	GNR	100DAP	100	3629	3225.78
6	GNR	100DAP	100	4452	3957.33
7	GNR	100DAP	100	3718	3304.89
8	GNR	100DAP	100	2908	2584.89
9	GNR	125DAP	125	5990	5324.44
10	GNR	125DAP	125	2936	2609.78
11	GNR	125DAP	125	4350	3866.67
12	GNR	125DAP	125	4303	3824.89
13	GNR	150DAP	150	3070	2728.89
14	GNR	150DAP	150	6207	5517.33
15	GNR	150DAP	150	2415	2146.67
16	GNR	150DAP	150	3171	2818.67
17	GNR	200D	200	5310	4720.00
18	GNR	200D	200	3742	3326.22
19	GNR	200D	200	6252	5557.33
20	GNR	200D	200	3882	3450.67
21	GNR	200DAP	200	6126	5445.33
22	GNR	200DAP	200	4028	3580.44
23	GNR	200DAP	200	3803	3380.44
24	GNR	200DAP	200	6013	5344.89
25	GNR	50DAP	50	3107	2761.78
26	GNR	50DAP	50	1677	1490.67
27	GNR	50DAP	50	3917	3481.78
28	GNR	50DAP	50	2792	2481.78
29	GNR	75DAP	75	5817	5170.67
30	GNR	75DAP	75	2900	2577.78
31	GNR	75DAP	75	3021	2685.33
32	GNR	75DAP	75	2201	1956.44
33	LB	0DAP	0	4328	3847.11
34	LB	0DAP	0	1520	1351.11
35	LB	0DAP	0	2290	2035.56
36	LB	0DAP	0	1795	1595.56
37	LB	100DAP	100	5074	4510.22
38	LB	100DAP	100	4975	4422.22
39	LB	100DAP	100	5137	4566.22
40	LB	100DAP	100	4635	4120.00
41	LB	125DAP	125	3763	3344.89
42	LB	125DAP	125	4350	3866.67
43	LB	125DAP	125	3833	3407.11
44	LB	125DAP	125	3554	3159.11
45	LB	150DAP	150	6500	5777.78
46	LB	150DAP	150	6799	6043.56
47	LB	150DAP	150	4473	3976.00
48	LB	150DAP	150	4536	4032.00
49	LB	200D	200	6300	5600.00
50	LB	200D	200	7562	6721.78

Obs	Soil	Treat	rate	Wtplot (g/plot)	Yield (kg/ha)
51	LB	200D	200	4926	4378.67
52	LB	200D	200	4801	4267.56
53	LB	200DAP	200	7342	6526.22
54	LB	200DAP	200	5564	4945.78
55	LB	200DAP	200	5639	5012.44
56	LB	200DAP	200	5618	4993.78
57	LB	50DAP	50	3246	2885.33
58	LB	50DAP	50	6284	5585.78
59	LB	50DAP	50	4495	3995.56
60	LB	50DAP	50	3688	3278.22
61	LB	75DAP	75	2690	2391.11
62	LB	75DAP	75	4174	3710.22
63	LB	75DAP	75	4836	4298.67
64	LB	75DAP	75	4077	3624.00
65	LW	0DAP	0	4092	3637.33
66	LW	0DAP	0	4705	4182.22
67	LW	0DAP	0	5688	5056.00
68	LW	0DAP	0	2904	2581.33
69	LW	100DAP	100	6000	5333.33
70	LW	100DAP	100	6249	5554.67
71	LW	100DAP	100	5539	4923.56
72	LW	100DAP	100	4103	3647.11
73	LW	125DAP	125	5006	4449.78
74	LW	125DAP	125	3369	2994.67
75	LW	125DAP	125	6263	5567.11
76	LW	125DAP	125	6096	5418.67
77	LW	150DAP	150	5308	4718.22
78	LW	150DAP	150	7128	6336.00
79	LW	150DAP	150	5303	4713.78
80	LW	150DAP	150	6359	5652.44
81	LW	200D	200	3758	3340.44
82	LW	200D	200	6021	5352.00
83	LW	200D	200	4457	3961.78
84	LW	200D	200	4241	3769.78
85	LW	200DAP	200	3357	2984.00
86	LW	200DAP	200	8394	7461.33
87	LW	200DAP	200	5698	5064.89
88	LW	200DAP	200	5736	5098.67
89	LW	50DAP	50	5297	4708.44
90	LW	50DAP	50	4542	4037.33
91	LW	50DAP	50	6284	5585.78
92	LW	50DAP	50	3351	2978.67
93	LW	75DAP	75	4609	4096.89
94	LW	75DAP	75	6118	5438.22
95	LW	75DAP	75	7299	6488.00
96	LW	75DAP	75	3984	3541.33
97	MW	0DAP	0	962	855.11
98	MW	0DAP	0	231	205.33
99	MW	0DAP	0	227	201.78
100	MW	100DAP	100	3520	3128.89

Summary of Yield data from Field Trials

Obs	Soil	Treat	rate	GrainWt (g/plot)	Yield (kg/ha)
101	MW	100DAP	100	293	260.44
102	MW	100DAP	100	358	318.22
103	MW	125DAP	125	893	793.78
104	MW	125DAP	125	1987	1766.22
105	MW	125DAP	125	353	313.78
106	MW	150DAP	150	3772	3352.89
107	MW	150DAP	150	594	528.00
108	MW	150DAP	150	154	136.89
109	MW	200D	200	1339	1190.22
110	MW	200D	200	766	680.89
111	MW	200D	200	1001	889.78
112	MW	200DAP	200	4111	3654.22
113	MW	200DAP	200	2550	2266.67
114	MW	200DAP	200	272	241.78
115	MW	50DAP	50	2099	1865.78
116	MW	50DAP	50	1216	1080.89
117	MW	50DAP	50	127	112.89
118	MW	75DAP	75	325	288.89
119	MW	75DAP	75	1285	1142.22
120	MW	75DAP	75	152	135.11

Appendix 12. Mean Maize Grain Yields and RAE of treatments in Field trials

Soil	Treat	Obs	Variable	Mean	Std Error
GNR	0DAP	4	Yield	414.2222222	109.1380370
			RAE	0.000577291	2.8351961
	100DAP	4	Yield	3268.22	280.6190394
			RAE	74.1420019	7.2899423
	125DAP	4	Yield	3906.44	555.3003710
			RAE	90.7217864	14.4256344
	150DAP	4	Yield	3302.89	753.0250762
			RAE	75.0425752	19.5621415
	200D	4	Yield	4263.56	533.9775739
			RAE	99.9988454	13.8717092
	200DAP	4	Yield	4437.78	554.6014325
			RAE	104.5248033	14.4074773
	50DAP	4	Yield	2554.00	412.2940938
			RAE	55.5878838	10.7106067
	75DAP	4	Yield	3097.56	709.4610834
			RAE	69.7084105	18.4304329
LB	0DAP	4	Yield	2207.33	564.6361150
			RAE	0.0010984	18.6059945
	100DAP	4	Yield	4404.67	99.4088701
			RAE	72.4080359	3.2757396
	125DAP	4	Yield	3444.44	150.2752481
			RAE	40.7666143	4.9518980
	150DAP	4	Yield	4957.33	553.1926044
			RAE	90.6196109	18.2289058
	200D	4	Yield	5242.00	578.2727652
			RAE	100.0000000	19.0553519
	200DAP	4	Yield	5369.56	385.8111225
			RAE	104.2032344	12.7133200
	50DAP	4	Yield	3936.22	595.9506014
			RAE	56.9717673	19.6378753
	75DAP	4	Yield	3506.00	400.7210579

Soil	Treat	Obs	Variable	Mean	Std Error
LB	75DAP	4	RAE	42.7950044	13.2046350
LW	0DAP	4	Yield	3864.22	517.9077090
			RAE	0.0091903	214.1884653
	100DAP	4	Yield	4864.67	426.3857679
			RAE	413.7579267	176.3382001
	125DAP	4	Yield	4607.56	591.9566773
			RAE	307.4257881	244.8125216
	150DAP	4	Yield	5355.11	394.4918699
			RAE	616.5885488	163.1480024
	200D	4	Yield	4106.00	435.1663227
			RAE	100.0000000	179.9695296
	200DAP	4	Yield	5152.22	914.8623319
			RAE	532.6808198	378.3549760
	50DAP	4	Yield	4327.56	550.1461684
			RAE	191.6276078	227.5211614
	75DAP	4	Yield	4891.11	664.7100671
			RAE	424.6944215	274.9007722
MW	0DAP	3	Yield	420.7407407	217.1876105
			RAE	0.0081547	43.4722999
	100DAP	3	Yield	1235.85	946.6654611
			RAE	163.1608991	189.4846800
	125DAP	3	Yield	957.9259259	427.2419989
			RAE	107.5312102	85.5168132
	150DAP	3	Yield	1339.26	1013.13
			RAE	183.8589390	202.7873415
	200D	3	Yield	920.2962963	147.8215660
			RAE	99.9992587	29.5879836
	200DAP	3	Yield	2054.22	990.7982898
			RAE	326.9660173	198.3183126
	50DAP	3	Yield	1019.85	506.9349084
			RAE	119.9263114	101.4681562
	75DAP	3	Yield	522.0740741	313.2356384
			RAE	20.2910477	62.6972855

Appendix 13. ANOVA for RAE of DAP on Chibombo Lixisols in field trials

```
                              The ANOVA Procedure

                            Class Level Information

      Class         Levels    Values

      Treat              8    0DAP 100DAP 125DAP 150DAP 200D 200DAP 50DAP 75DAP

                          Number of observations    32

Dependent Variable: RAE

                                       Sum of
       Source                 DF         Squares     Mean Square    F Value    Pr > F

       Model                   7     30639.02282      4377.00326       5.81    0.0005

       Error                  24     18076.26691       753.17779

       Corrected Total        31     48715.28974

                  R-Square     Coeff Var      Root MSE      RAE Mean

                  0.628941      38.53648      27.44408      71.21586
```

Appendix 14. Mean Comparisons for RAE of DAP on Chibombo Lixisols in field trials

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                               t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.
                              Alpha                            0.05
                              Error Degrees of Freedom           24
                              Error Mean Square            753.1778
                              Critical Value of t           2.06390
                              Least Significant Difference   40.052
                   Means with the same letter are not significantly different.

                      t Grouping          Mean      N    Treat

                               A        104.52      4    200DAP
                               A
                               A        100.00      4    200D
                               A
                          B    A         90.72      4    125DAP
                          B    A
                          B    A         75.04      4    150DAP
                          B    A
                          B    A         74.14      4    100DAP
                          B    A
                          B    A         69.71      4    75DAP
                          B
                          B              55.59      4    50DAP

                               C          0.00      4    0DAP
```

Appendix 15. ANOVA for RAE of DAP on Chongwe Lixisols from field trials

The ANOVA Procedure

Class Level Information

Class	Levels	Values
Treat	8	0DAP 100DAP 125DAP 150DAP 200D 200DAP 50DAP 75DAP

Number of observations 32

Dependent Variable: RAE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	35296.21922	5042.31703	5.61	0.0006
Error	24	21581.65531	899.23564		
Corrected Total	31	56877.87453			

R-Square	Coeff Var	Root MSE	RAE Mean
0.620562	47.24585	29.98726	63.47067

Appendix 16. Mean Comparisons for RAE of DAP on Chongwe Lixisols in field trials

t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	24
Error Mean Square	899.2356
Critical Value of t	2.06390
Least Significant Difference	43.763

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	104.20	4	200DAP
B A	100.00	4	200D
B A	90.62	4	150DAP
B A C	72.41	4	100DAP
B C	56.97	4	50DAP
D C	42.80	4	75DAP
D C	40.77	4	125DAP
D	0.00	4	0DAP

Appendix 17. ANOVA for RAE of DAP on Chilanga Phaeozems in field trials

The ANOVA Procedure

Class Level Information

Class	Levels	Values
Treat	8	0DAP 100DAP 125DAP 150DAP 200D 200DAP 50DAP 75DAP

Number of observations 32

Dependent Variable: RAE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1281165.578	183023.654	0.78	0.6066
Error	24	5596801.606	233200.067		
Corrected Total	31	6877967.183			

R-Square	Coeff Var	Root MSE	RAE Mean
0.186271	149.3462	482.9079	323.3480

Appendix 18. Mean Comparisons for RAE of DAP on Chilanga Phaeozems in field trials

t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	24
Error Mean Square	233200.1
Critical Value of t	2.06390
Least Significant Difference	704.75

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	616.6	4	150DAP
A			
A	532.7	4	200DAP
A			
A	424.7	4	75DAP
A			
A	413.8	4	100DAP
A			
A	307.4	4	125DAP
A			
A	191.6	4	50DAP
A			
A	100.0	4	200D
A			
A	0.0	4	0DAP

Appendix 19. ANOVA for RAE of DAP on Rufunsa Acrisols in field trials

The ANOVA Procedure

Class Level Information

Class	Levels	Values
Treat	8	0DAP 100DAP 125DAP 150DAP 200D 200DAP 50DAP 75DAP

Number of observations 24

Dependent Variable: RAE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	219584.030	31369.147	0.59	0.7513
Error	16	843974.725	52748.420		
Corrected Total	23	1063558.756			

R-Square	Coeff Var	Root MSE	RAE Mean
0.206462	179.8264	229.6702	127.7177

Appendix 20. Mean Comparisons for RAE of DAP on Rufunsa Acrisols in field trials

t Tests (LSD) for RAE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	52748.42
Critical Value of t	2.11991
Least Significant Difference	397.54

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	327.0	3	200DAP
A			
A	183.9	3	150DAP
A			
A	163.2	3	100DAP
A			
A	119.9	3	50DAP
A			
A	107.5	3	125DAP
A			
A	100.0	3	200D
A			
A	20.3	3	75DAP
A			
A	0.0	3	0DAP