Assessing the productivity of grain cowpea under variable conditions using low-input agricultural production practices

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DECLARATION

I, Kagiso Ephraim Moeta, declare that the dissertation entitled "Assessing the productivity of cowpea grains grown under variable conditions using low-input agricultural practices", hereby submitted to the North-West University for the degree of Master of Science in Crop Sciences (Agronomy) in the Faculty of Natural and Agricultural Sciences, School of Environmental and Health Sciences, has not previously been submitted by me for a degree at this or any other university. I further declare that this is my original work in design and execution and that all materials contained herein, have been duly acknowledged.

Name: Kagiso Ephraim Moeta

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Date: ....

DEDICATION

I dedicate this study to my late grandmother Mrs R. A Moeta, my mother Ms C. M Moeta and my brother Mr R. J Moeta

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ABSTRACT

The adoption of low-input agricultural practices can play a vital role towards ensuring food security. Cowpea is an indigenous crop that is highly adaptive and has numerous benefits. However, its production in South Africa is still very low with smallholder farmers being the largest producers of the crop in the country. The study focused on efforts to maximise the production of cowpea, particularly for smallholder farmers using low-input agricultural practices, which could ensure sustainable production and enhance food security. The aim of this study was to investigate the impact of low-input agricultural practices on the productivity of grain cowpea grown under tunnel house and dryland conditions. Phospho-compost prepared at the Molelwane experimental farm of North-West University using animal manure (cattle, sheep and poultry) and sawdust through co-composting with ground phosphate rock in heap was used for tunnel house and field trials.

A repeated 2x2x6 factorial trial was carried out under tunnel house conditions with one field trial conducted under dryland conditions (these were all done at Molelwane). The tunnel house trials treatment factors consisted of six phosphorus (P) fertilizer rates, two soil types and moisture regimes, replicated three times to obtain 72 pots for both trials. The P fertilizer treatments comprised of variable phospho-compost rates (0, 10, 20, 40 and 80 t/ha) with 30 kg P/ha rate applied as single super phosphate (SSP 10.5%) included as a standard positive control. The soils used in tunnel house trial 1 were from a smallholder farmer's field in Ventersdorp (Glenrosa) and the North-West University experimental farm (Hutton) while the soils for the second tunnel house trial comprised Coega and Hutton soil types collected from the North-West University, Mafikeng Campus. The different P fertilizer rates exerted significant ($p \leq 0.05$) influence on all cowpea growth parameters, with the exception of leaf length. Variation in soil types used in the tunnel house trials exerted significant ($p \leq 0.05$) effect on stem diameter and chlorophyll content. The highest seed yield (12.51 g/pot) and (8.50) number of pods per plant were recorded in the 40 t/ha phospho-compost rate. Cowpea plants grown under the Coega and Glenrosa soil types performed better than those grown under Hutton soil. Application of 30 kg P/ha resulted in the highest mean nodule count (34.3) under tunnel house 1 while moisture stress exerted a depressive effect on cowpea seed yield, number of pods and fodder weight. Results obtained revealed that moisture-deprived plants flowered and formed pods quicker

The field trial was carried out during 2017-2018 summer growing season, the trial also comprised six phosphorus (P) fertilizer rates and two tillage practices (minimum and conventional). The P fertilizer treatments under the field trial also consisted of variable phospho-compost rates (0, 10, 20, 40 and 80 t/ha) with 30 kg P/ha rate applied as single super phosphate (SSP 10.5%) included as a positive control. Rainfall was used as the main source of irrigation with supplementary irrigation used only when there was a need. Application of 40 and 80 t/ha phospho-compost rates significantly increased the residual Bray P content, organic carbon and total N soil content after harvest. Seed germination and plant emergence was quicker under minimum tillage. Tillage and different fertilizer rates significantly influence all the measured cowpea growth parameters and yield attributes. The highest grain yield (488.06 kg/ha) and nodule count (15.36) under field conditions were produced at 40 t/ha phospho-compost rate while minimum tillage gave higher grain yield (611.66 kg/ha) and nodule count (14.39) than conventional tillage. Application of phospho-compost resulted in significant increase soil available P and cowpea plant tissue P content. The heavy metal content of cowpea grains from the different fertilizer rates and tillage practices did not differ significantly ($p>0.05$) with measured values generally within the threshold level required for human consumption albeit the high Al and Fe concentrations in soil suggesting phyto-toxicity, which may have resulted in low grain yield obtained.

Keywords: Phospho-compost, Cowpea, Moisture stress, Dryland farming, Tillage, P-availability, Soil types, Grain yield

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CHAPTER 1: GENERAL INTRODUCTION AND STUDY OBJECTIVES

1.1 Background of the study

Cowpea (Vigna unguiculata (L.) Walp) is one of the numerous indigenous crops in South Africa despite its well-known nutritional advantages, including its potential capability to contribute to human diet and improvement of soil fertility through nitrogen (N) fixation (Sebetha et al., 2010). Its fodder is also useful as livestock feed (Asiwe et al., 2009). The crop is an important legume grown worldwide with huge potential for promoting food security globally. According to Abayomi et al. (2008), cowpea is highly valuable for over 200 million people in the dry savannah regions of tropical Africa; occupying over 6 million hectares in West Africa. In South Africa, cowpea is also grown but mostly by small-scale farmers and households in rural areas (Asiwe 2007). This crop is an excellent and cheap plant source of protein for humans (Sebetha et al., 2010); and it is often served with maize meal, rice and/or used as a vegetable (Asiwe et al., 2009). As noted by Singh (2003), cowpea is an ancient legume crop, broadly adapted and cultivated all over the world, primarily as a pulse but also as a green peas source consumed as a vegetable. Thus, its increased production could generate income to support families, as such, the breeding of high yielding cowpea varieties which could contribute towards food security, while also alleviating poverty (Asiwe et al., 2009).

Sustainable agricultural production relies on soil replenishment while minimizing the use of or need for non-renewable resources (Kassie et al., 2009). Agricultural practices that promote increased and sustainable crop production and also preserve the soil as a natural resource are urgently needed to guarantee both the present and future food production. This is important because of the reported high rate of soil losses, which is estimated to be about 13 t/ha per year in South Africa (Laker 2003), leading to the reduction in the quality and productivity of the limited available arable land (Mukheiber and Sparks 2003) under a very harsh prevailing environment. Practices such as the use of minimum (reduced) tillage, low-input cost like growing legume cover crops and using phosphorus (P)-enriched composts could be considered as appropriate land management practices that can help protect the soil by reducing erosion and also improve soil fertility (Laker 2003). Attempts to stabilize soil and maintain fertility for sustainable crop production in the light of the recent challenge of climate change vulnerability informed the drive for the adoption of climate smart agricultural practices. Such practices include increase crop residues recycling, the use of manure/compost and the growing of leguminous cover crops such as cowpea that has the ability to cover the soil quickly and also fix N (Singhal et al., 2015). Such practices and inputs, through proper management, represent cheaper and environmentally safe alternatives sources of nutrients to inorganic fertilizers that could be used to increase crop yields at low cost and protect scarce environmental resources such as soil and water. Hence, they are collectively described as low-input technology.

Due to the increasing human population, not just in Africa, but globally, and the scarcity of arable land for agricultural production, there is a growing need to adopt practices that will ensure sustainable production while preserving natural resources. This could be done through the adoption of low-input agriculture practices. One of the most common low-input agricultural practices is the use of compost as a replacement for organic fertilizers. Compost originates from nature and, as such it can only be good for the soil and plants (Jacobsen 2005). Composts produced from organic wastes have recently been proved to have better quality than commercial inorganic fertilizers (Chowdhury et al., 2015). According to Hermann et al. (2011), composts can be used as substitute for soil conditioners in support of humus formation, which is a benefit that cannot be achieved through artificial means.

Composting is a technology that transforms organic waste to organic manure (compost), it recycles mineral nutrients such as N, P and potassium (K) that could be utilized for agricultural production (Wang et al., 2015). This makes compost a serious competitor in the fertilizer market (Proietti et al., 2016). There are several benefits to using compost instead of inorganic fertilizers; it helps decrease environmental problems related to wastes management by decreasing waste volumes and killing potentially dangerous organisms. Other advantages of using compost is that it reduces the rate of mineralization, as such Nitrate leaching may decrease by delaying the conversion of organic N to the mobile nitrate N (Evanylo et al., 2008). Wander et al. (2002) stated that using compost to add organic matter of the soil, can help restore and maintain the soil quality.

Composting reduces dissemination of pathogens, germination of weeds and it destroys evil-smelling compounds. Composting is to produce a stable product that is valuable to farmers and gardeners, that can be used instead of fertilizers and it also helps protect the soil structure. Compost provides great value to the environment and it leads to increased potential for soils to retain moisture in periods of rainfall, reducing the likelihood of flooding associated with moisture run-off (Favoino and Hogg 2008). Composting is also used to supply nutrients to crops.

Low-input agricultural practices can prove particularly useful for smallholder farmers who are resource-poor and require alternative farming practices to be able to sustain and enhance their production. Wiggins and Keats (2013) argued that smallholder farmers have an important role in improving household food security, especially in improving nutrition. Smallholder farming can play an important role in the future of global food security, especially in rural areas. Many poor people live in rural areas with little or no access to productive agricultural lands (Tscharntke et al., 2012), which further exacerbates the problem of food insecurity. Farm sizes and hunger are linked and approximately 90% of farmers worldwide farm on less than 2 hectares of land, producing food where it is required – in much of the developing countries (Tscharntke et al., 2012). Eighty percent of food insecurity occurs developing countries with 50% of the population involved in small-scale farming (World Bank 2007). Therefore, smallholder farmers as opposed to large-scale commercial farmers have a crucial role to play towards achieving global food security (Horlings and Marsden 2011; Chappell and LaValle 2011) and this can be achieved with the aid of low-input agricultural practices that will not only help preserve natural resources and protect the environment but also ensure sustained agricultural production.

1.2 Problem statement

South Africa is a country largely dominated by dryland areas. The problems of crop failure and low yields in these dry areas, in recent years, are aggravated by low soil fertility, particularly N and P deficiency, and climate change that has recently resulted in droughts and extensive heat waves. The impact of climate-soil combinations had seriously affected only 12% of the country's agricultural lands that is suitable for crop production under dryland conditions, with only 3% considered truly fertile land and about 69% of the land surface considered suitable for grazing (Mukheiber and Sparks, 2003). Due to the high vulnerability of the less suitable agricultural lands to erosion, rapid soil fertility decline estimated at about 13 tons/ha/year (Laker, 2003) and land degradation, the escalated problem of low agricultural productivity has widened, particularly among subsistence and small-scale farmers (Kutu, 2012) thus worsening food insecurity and poor health challenges among the most vulnerable rural people. The low to non-use of inorganic fertilizer and the high dependence on the use of manure, often applied at suboptimal level further exacerbate the situation (Kutu, 2012).

Agricultural practices that can promote sustainable crop production and preserve the soil, as a natural resource in South Africa, are urgently needed to satisfy the food and fibre as well as nutritional demand for the ever-growing human and animal population. Cowpea is a crop that is reported to have the potential to be very productive under a low-input farming system (Jeranyama et al., 2000). Yet, it is regarded as a useful crop to small-scale farmers who produce food for vulnerable rural poor communities provided proper land and resource management is practised because of its many important uses (Abayomi et al., 2008). Regrettably, its cultivation and yields in South Africa have remained low due to limited or virtually no research attention, particularly at the level of subsistence and small-scale farming.

1.3 Justification for the study

This study primarily targets the resource-poor subsistence and smallholder farmers, including emerging farmers who are rural-based; and are also responsible for producing food under resource-poor farming conditions (Jacobs, 2008). In South Africa, cowpea is mainly grown as a vegetable crop by smallholder farmers and for fodder by isolated pockets of commercial farmers. Its production as a grain legume can go a long way in addressing food security challenges in many poverty-ridden rural communities due to its numerous nutritional benefits including its high protein content that is sometimes b higher than that of meat (Sebetha et al., 2010; Adeyemi et al., 2012). Thus, increase and sustainable cowpea production in many rural communities will greatly contribute towards food security and the well-being of the people. The findings emanating from this study could potentially contribute towards eliminating hidden hunger of mineral deficiency, which is regarded as a major global health issue for human beings in many developing countries (Farooq et al., 2012).

1.4 Aim of the study

This aim of the study was to investigate the impact of low-input agriculture practices on grain cowpea productivity under tunnel house and dryland field conditions.

1.5 Objectives of the study

The specific objectives of the study were to:

i. Evaluate the growth and yield of cowpea in response to the application of P-enriched compost as a low-input agricultural practice;

ii. Determine the impact of dry land field conditions on grain cowpea production, and

iii. Evaluate the productivity of grain cowpea grown under greenhouse conditions.

1.6 Hypotheses

The following hypotheses were stated in the study:

i. Addition of P-enriched compost will result in an increase in the growth and productivity of cowpea and, as such an increase in yields;

ii. The productivity of grain cowpea is not negatively affected by dryland conditions and

iii. The productivity of grain cowpea is not negatively affected by tunnel house conditions

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CHAPTER 2: LITERATURE REVIEW

2.1 Cowpea as an important food crop

Cowpea is a warm-season, annual, herbaceous legume categorized as erect, semi-erect, prostrate (trailing), or climbing (Horst and Haerdter 1994). It generally has taproot and it is adapted to awide range of soils. It has a striate stem that is smooth or slightly hairy with some purple shades, the first pair of leaves is basic and opposite with the rest arranged in alternate patterns and are trifoliate (Quass 1995). The leaves are usually dark green in colour, showing substantial variation in size and shape, ranging from linear- lanceolate to oval-like shape with leaf petiole that is 5 to 25 centimetres long (Quass 1995). Cowpea also grows well in nutrients-poor soils containing low organic matter and P levels (Jeranyama et al., 2000). It is shade tolerant and very valuable in intercrops, with crops such as maize and sorghum and thus, serves as an ideal crop for resource-poor small-scale farmers, who mostly rely on rainwater for their agricultural activities (Singh 2003). Cowpea is commonly known as Dinawa, Dinaba, Munawa, Imbumba, the seed colour varies and it can be red, black, brown, green, white, spotted or blotched.

Cowpea is cultivated worldwide, and it is a self-pollinating plant (Mahe et al., 1994; Musvosvi 2009). It is drought tolerant and it has the ability to grow poor-quality soils, it is one of the most important grain legumes in semi-arid tropics. The crop improves soil fertility through biological Nitrogen fixation (Davis et al., 1991; Nhamo and Mupangwa 2003; Dumet et al., 2008; Musvosvi 2009), cowpea can function as a sole-crop but it can also be effectively intercropped with sorghum, millet, maize, cassava or cotton (Singh et al., 1997).

Cowpea is a dicotyledonous legume belonging to the genus Vigna within the family of Fabaceae and it originates in Africa (Padulosi and Ng 1997). Pasquet (1997, 1998) divided cowpea into eleven perennial and one annual subspecies (ssp. unguiculata) that includes cultivated (var. unguiculata) and wild forms (var. spontanea). Ng and Marechal (1985) hypothesized that there were two independent centres for primary domestication of cowpea: one in the Zambezian region in eastern Africa and another in western Africa. Morphological diversity of the variety spontanea is highest between Ethiopia and South Africa, as such the whole eastern part of the African continent was supposed to be the centre of domestication (Baudoin and Marechal 1985).

Propagation of cowpea is done through seeds, covered by pods. Pods and subsequently seeds from wild cowpea varieties are very small, however there is high variation between cultivated varieties (Quass, 1995). The number of seeds per pod may vary from 8 to 20 seeds, and are usually kidney-shaped. When the seeds become spherical, they become restricted within the pod (Quass 1995). Their texture and colour is very diverse, they can have a smooth or rough coat, and be speckled, mottled or blotchy (Quass 1995).

2.2 Crop requirements for successful production

Cowpea thrives in poor dry conditions and this makes it an important crop particularly in arid, semi-desert regions where not many other crops will grow (Singh et al., 2003). The optimum temperature for cowpea growth is 30 °C, as such it is better suited warmer climates. It grows best where annual rainfall ranges between 400–700 mm, rainfall has to be well-distributed for normal growth and development of cowpeas (Quass 1995). Adequate rainfall is particularly important during the flowering/podding stage. Moisture stress by limits plant growth (especially the leaf growth) and thus it reduces the leaf area.

Cowpea is a heat-loving and drought-tolerant crop and the base temperature for germination is 8.5°C and for leaf growth 20°C. (Quass 1995). Cowpea requires temperatures between 28 and 30°C (night and day) during the growing season (Dugjie et al., 2009). Cowpeas can be grown on a wide range of soils but the crop shows a preference for sandy soils, which does not restrict root growth and it grows well even in poor soils with more than 85% sand, less than 0.2% organic matter and low levels of phosphorus (Kolawale et al., 2000; Sanginga et al., 2000). It tolerates infertile and acid soils better than most crops (Quass 1995). The timing of planting is crucial as the plant must mature during seasonal rains. It performs best on well-drained sandy loam and sandy soils where soil pH is in the range of 5.5 to 6.5 (Singh 2003) and less on heavy soils. It is well adapted to drier regions of tropics where other food legumes do not perform (Asiwe 2007). Cowpea has the potential capability to contribute to soil fertility through nitrogen (N) fixation (Sebetha et al., 2010), thus does not require too much nitrogen fertilizers. However, production and high yields of cowpea depends on the availability of phosphorous (P) in the soil since the nutrient is important/critical for nodule formation towards symbiotic n-fixation, improving seed quality and overall yield (Singh et al., 1997).

The cowpea variety to be planted and its growing pattern determines the inter-row and intra-row spacings to be used. More space between plant and rows is required with trailing types compared to the upright growing pattern (Quass 1995). Generally, for grain production, a plant population of 200 000 to 300 000/ha at 30 to 50 cm inter-row spacing is preferred to wider rows (70 to 100 cm), which is suitable for trailing varieties (Quass 1995). Cowpea should be planted between late November and early December in lower rainfall areas of South Africa in order to achieve optimum yields (Quass 1995). The seeds must be sorted before planting to make sure they are free from insect damage (without damage holes or wrinkles) or any inert materials, and they must be planted at a depth of 3-4 cm.

2.3 Benefits of growing and utilizing the crop

There are a number of advantages associated with growing cowpea. It is an excellent cheap protein source for humans (Sebetha et al., 2010) hence why it is even referred to as a poor man's meat, it is often served with maize meal, rice and it can also be as a vegetable (Asiwe et al., 2009). Cowpea can be utilized at different growth stages before it reaches harvest maturity, thus making it a highly valuable crop. The seeds contain a lot of plant proteins and vitamins and they have a very high level of folic acid (Timko and Singh 2008) and a source of income. The young leaves are consumed as leafy vegetables (locally referred to as morogo) in many parts of South Africa while immature pods are used and sold as green beans or vegetables (Dugjie et al., 2009). The leaves are rich in vitamins and minerals (Ahenkora et al., 1998). Furthermore, fresh vegetative biomass can be used to produce hay (Badiane et al., 2014). In Southern Africa, cowpea is used for the production of fodder, which can be subsequently used for grazing, and in some instances, to make hay and silage.

Mature cowpea pods are harvested and the haulms cut while still green and rolled into small bundles containing leaves and vines in West African countries (Singh et al., 2003). Haulms, therefore, constitute an important source of income and they have a high nutritive value. The crude protein content of cowpea grains and leaves ranges from 22 to 30% on a dry weight basis (Bressani 1985; Nielsen et al., 1997), and from 13 to 17% in the haulms, also being highly digestible and with low fibre levels (Singh et al., 2003).

Cowpea plants grow fast and this allows them to cover the soil quicker, thus leading to the soil being protected from erosion while also preserving soil moisture. This fast growth also allows cowpea to suppress weeds as it is also used as a weed control practice in forestry plantations (Kay, 1979). Cowpea can be a valuable component of crop rotations because its resistant cultivars to help the suppress the reproduction of root-knot nematodes (*Meloidogyne* spp). Singh (2003) stated that cowpea has the beneficial ability of fixing atmospheric nitrogen through its root nodules (Asiwe et al., 2009), thus eliminating the need for farmers to buy Nitrogen fertilizers and saving a lot of money on the cost of inputs (Dugjie et al., 2009).

Cowpea is shade tolerant and, therefore, compatible as an intercrop with maize, millet, sorghum, sugarcane and cotton as well as with several plantation crops (Singh and Emechebe 1998; Singh et al., 2003). The quick growth and rapid ground cover of cowpea helps reduce soils erosion, while root decay in situ produces nitrogen-rich residues of cowpea improves soil fertility and structure (Singh et al., 2003).

2.4 Challenges associated with the production of cowpea

Cowpea plants are subjected to both biotic and abiotic stress. Lack of adoption by farmers is one of the biggest constraints towards the production of cowpea, based largely on the evidence that cowpea is mainly grown by rural smallholder farmers under dryland conditions and not by many commercial farmers (Quass 1995). Lack of research on cowpea as well as the current lack of improved varieties also poses a serious challenge towards adoption and production of the crop. Planting cowpea successively on the same land can have adverse effects, such as increasing its susceptibility nematode infection (Dugjie et al., 2009). Subjecting cowpea to moisture stress during the reproductive stage causes a sharp decline in flowering and grain filling (Dugjie et al., 2009)

Cowpea it not well adapted to waterlogging and should not be grown soils with poor drainage (Dugjie et al., 2009). Weeds also pose a problem towards the production of cowpea, if not properly managed. They harbour pests and diseases, which leads to a reduction in the yield and quality of the grain while fodder can also be affected. During the early stages of growth, cowpea cannot compete strongly with weeds (Dugjie et al., 2009). Two of the most damaging parasitic weeds that attack cowpea are Striga and Alectra but Striga has a more devastaing effect than Alectra (Dugjie et al., 2009).

Insect pests are also responsible for the low yields of African cowpea crops, and they affect the plant at different developmental stages (Quass 1995). In bad infestations, insect pressure can cause approximately 90% loss in grain yields). Various Fungal, bacterial and viral diseases affect cowpea. The major and common diseases are anthracnose, Sclerotium stem, root and crown rot, damping off, Cercospora leaf spot, Septoria leaf spot, Fusarium wilt and scab (Dugjie et al., 2009). Aphids also pose a serious threat to the production of cowpea while cowpea aphid only causes direct damage to the cowpea plant but also transmits cowpea aphid-borne mosaic virus (Dugjie et al., 2009). Blister beetles feed on cowpea flowers, leading to considerable crop damage (Dugjie et al., 2009). Maruca pod borer (*Maruca testulalis*) is prevalent in the tropics and subtropics where it may cause extreme damage. Podsucking bugs (*Anoplocnemis curvipes*) are major cowpea pests in tropical African regions and can lead to yield losses of about 30 to 70% (Dugjie et al., 2009).

2.5 Agricultural production under dryland

Dryland areas are defined by water scarcity, higher evaporation from surfaces, higher transpiration by plants and an aridity index of less than 0.65 (Rodriguez-Iturbe and Porporato 2004). Dryland areas are generally complex and contain evolving structures and characteristics that depend on the interrelated links between climate, soil and vegetation. Cultivation and farming activities on these lands depend largely on rainfall for water (Molden 2007). South Africa is a dry country, with pronounced spatial and temporal variability, and east–west rainfall gradient ranging from more than 1 000 mm to less than 250 mm per year (Mukheiber and Sparks 2003). Dryland ecosystems play a big role in the global biophysical processes by reflecting and absorbing solar radiation while also maintaining the balance of atmospheric constituents (Ffolliott et al., 2002).

Sub-Saharan Africa (SSA) is associated with physical and economic scarcity of water, with the latter affecting more than 75% of the region (Hanjra and Qureshi 2010). The greater proportion of agriculture is resource-constrained, subsistence-based and it is done under rainfed conditions (Van Duivenbooden et al., 2000). Under these conditions, there are high yield losses which are linked to water stress (Rockström et al., 2003). This increases the risk to food production in a region already overwhelmed with food insecurity problems and a variety of socio–economic production constraints (Ortmann and King 2010). Maximising crop productivity with the available water is a major priority, particularly if food security is to be attained.

Portions of dryland in South Africa that is currently being cultivated includes the Free State, Eastern Cape and the North-West Province (Hoffman and Meadows 2003). The most important factor that limits agricultural production in South Africa is non-availability of water, with uneven rainfall distribution across the country (Hoffman and Meadows 2003). Characteristics of dry lands include low soil natural fertility, which results in the absence of nutrients for crops, the soils have a low water holding capacity, making it harder for the soil to retain sufficient water, thus leading to situations whereby the amount of soil water available is no longer sufficient to satisfy crop needs. There is also high variability with regards to the amount and intensity of rainfall in drylands (Hoffman and Meadows 2003) and this can have a negative impact on agricultural production, thus resulting in issues such water erosion and could even damage the cultivated crops.

2.6 Production of cowpea in South Africa compared to the rest of the world

Cowpea is an important grain legume for over 200 million people in the dry savannah of tropical Africa; occupying over 6 million hectares in West Africa. In South Africa, cowpea is grown mostly by small-scale farmers and households in rural areas (Asiwe 2007). Asiwe (2007) reported that the land area provisioned for cowpea production by local farmers was small and it ranged from 0.25 to 2.00 hectares and very low grain yield of about 0.25 t/ha are obtained as such. The main cowpea producing areas in South Africa are Limpopo (Bohlabela, Vhembe, Mopani, Capricorn, Sekhukhune and Waterberg districts), Mpumalanga (Gert Sibande, Nkangala and Enhlazeni districts), North-West (Central, Bophirima and southern districts) and in Umgungundlovu district in Kwazulu-Natal (Quass 1995; DAFF 2011; Asiwe 2007).

Globally, cowpea production is estimated to be around 3.7 million tonnes annually on about 8.7 million hectares and about 87% of the total area is in Africa, with 10% being in America and the rest in Europe and Asia (Langyintuo et al., 2003). Nigeria is the world's largest cowpea producer, a large part of cowpea production comes from the drier regions of Nigeria (about 5 million hectares, with 2.1 Mt), Niger (about 3 million hectares, with 0.6 Mt) and Brazil (about 1.9 million hectares with 0.7 Mt) (Singh et al., 2003). Nigeria accounts for about 45% of the total cowpea produced globally, followed by Brazil, which produces 17% on 1.144 million hectares annually (Pereira et al., 2001; Langyintuo et al., 2003) while Niger accounts for 8%. Ghana, Niger and Cameroon are also significant cowpea producers. The major production areas elsewhere in the world are Asia (India, Myanmar) and the Americas (USA, Brazil and West Indies). Only USA is a substantial producer and exporter among the developed countries (Quass 1995).

The production of cowpea is widely distributed throughout the tropics. However, Central and West Africa account for more than 64 % of the area, with about 8 million hectares, followed by about 2,4 million hectares in Central and South America, 1,3 million hectares in Asia and 0,80 million hectares in East and Central Africa (Quass 1995). Niger, Burkina Faso, Benin, Mali, Cameroon, Chad and Senegal are net exporters; Nigeria, Ghana, Togo, Cote d'Ivoire and Mauritania are net importers. Official sources show that at least 285,000 tons of cowpeas were shipped between regions in 1998 (Langyintuo et al., 2003). Tariffs, fees, high transport costs and other factors constitute constraints to cowpea trade. Since production and consumption do not occur simultaneously, producers and traders need efficient storage and transportation systems to ensure timeliness of the availability of cowpea for consumers (Langyintuo et al., 2003).

Singh et al. (1997) reported on-farm trials yields of 2.8 t/ha in Nigeria while in Burkina Faso, average yields of about 83% less than experimental on-farm trial yields were reported (SAFGRAD 1998; Langyintuo et al., 2003). Cowpea is one of the mandate crops of the International Institute of Tropical Agriculture, Ibadan, Nigeria (Singh et al., 1997). Cowpea is regarded as the "fulcrum of sustainable farming" in semiarid lands, particularly in West and Central Africa where the area of cowpea production extends in a westerly direction from Cameroon through Senegal, covering the dry savannah of Northern Guinea and Sudan as well as Sahel zones (Langyintuo et al., 2003).

2.7 Sustainable agricultural production practices

Sustainable farming is defined as the production of food, fibre or other plant and animal products, using farming techniques that protect the environment based on an understanding of ecosystem services; and defined as an integrated system of long-term plant and animal production to satisfy human food and fibre needs (Kassie et al., 2009). Sustainable agricultural practices help conserve valuable resources such as land and water are environmentally non-degrading, technically appropriate, economically and socially acceptable (FAO 2008). Such practices use fewer external inputs such as synthetic fertilizers and other available natural resources that are easily accessible (Lee 2005). Sustainable agriculture requires soil fertility replenishment is suited for small-scale farmers since it relies on renewable local or farm resources for enhancing the agricultural productivity of resource-constrained farmers (Kassie et al., 2009).

The world's population increases at a rapid rate, particularly in Africa, which has put much pressure on food supply. The available agricultural land needs to be cultivated continuously to meet food demands resulting in soil quality deterioration besides the further loss of agricultural land due to infrastructural development (Ahamefule and Peter 2014). Thus, to maintain the quality and sustain the productivity of the diminishing agricultural land mass, the need for soil conservation becomes crucial, raising the need for the adoption of sustainable agricultural practices to cater for the ever-growing world population in the long-term (Ahamefule and Peter 2014).

These practices include crop rotation, which is growing different crops in succession in the same field, using reduced or zero tillage and replacing synthetic fertilizers with compost. Reduced tillage results in more sequestration on carbon dioxide, which, leads to reduced climate change and ultimately global warming (Environmental Indicators for Agriculture 2001). Reduced tillage helps improve the soil structure since soil life is not disturbed, thus resulting in better soil aeration, improved soil fertility and increased microbial activity and ultimately helps reduce the use of fossil fuels (Environmental Indicators for Agriculture 2001). Conventional tillage constitutes a problem in the long term even when it results in better yields, hence the need to adopt less intense tillage systems for prolonged cultivation (Ahamefule and Peter 2014).

2.7.1 Low-input agriculture practices

Low-input agriculture is characterized as a production activity that uses chemical fertilizers or pesticides below rates commonly recommended by the Extension Service (Tripp 2006; Ibeawuchi et al., 2005). Yields are maintained through larger emphasis on cultural practices, integrated pest management and utilization of on-farm resources and management (Tripp 2006). Pesticides and other chemicals are responsible for extensive environmental problems, including health risks and applied at minimal rates. Over-reliance on inorganic fertilizers often leads to soil degradation (Tripp 2006; Ibeawuchi et al., 2005) and ultimately to a decline in agricultural production. Farmers in sub-Saharan Africa (SSA) are generally small-scale entrepreneurs, whose farm operations are performed with low input agricultural technologies, majority of these technologies are refined indigenous knowledge systems (Ibeawuchi et al., 2005).

2.7.1.1 Utilization of compost as a low-input agricultural practice

The use of compost as one of the most common low-input agricultural practices could serve as an answer towards reducing the over-reliance on expensive synthetic fertilizers (Evanylo et al., 2008). One environmental advantage of compost as a soil amendment is the reduced mineralization rates which sdecrease the potential for nitrate leaching by delaying the conversion of organic N to mobile nitrate N (Evanylo et al., 2008). Wander et.al (2002) reported that increasing soil organic matter content through the addition of compost can help restore and maintain soil quality. Aref and Wander (1997) suggested that adding organic matter could also help improve environmental efficiency (entails using fewer input to obtain yields).

The objective of composting wastes is to reduce quantity, dissemination of pathogens, decrease germination of weeds and destroy evil-smelling compounds (Jakobsen, 1995). Furthermore, the purpose of composting is to produce compost that is valuable for farmers and gardeners to be used instead of fertilizers (Jakobsen, 1995; Evanylo et al., 2008). It is of great value to the environment to compost wastes and use the compost for protection of the soil structure and for supply of nutrients to the crop (Jakobsen 1995). Other benefits of the application of compost may have some relevance and such as the replacement of chemical fertilizers (implying avoidance of greenhouse gases related to their production), reduced use of pesticides (avoiding emissions associated with their production), improved tilth and workability (Jakobsen 1995).

Compost helps add organic matter to the soil, which, in turn improves the soil structure, thus leading to increased potential for soils to retain moisture in periods of rainfall, which reduces the risk of flooding associated with moisture run-off (Favoino and Hogg 2008). Generally organic matter is very important because of its influence on soil fertility, stability and structure. Proper application of organic fertilizers in agriculture, besides the adoption of proper cropping and tilling techniques, can have a positive effect on soil carbon levels (Favoino and Hogg 2008). Applications of organic matter can lead, depending upon the rate of application and other factors, either to a build-up of soil organic carbon over time, or a reduction in the rate at which organic matter is depleted from soils (Favoino and Hogg 2008).

Composting is the controlled aerobic biological decomposition of organic matter into a stable, humus-like product called compost. It is essentially the same process as natural decomposition, except for the enhanced and accelerated by mixing organic wastes with other ingredients to optimize microbial growth (USDA 2000). Soil application of compost achieves various benefits including recovery of degraded soils, soil fertility maintenance/increase, plant diseases suppression, soil carbon sequestration and reduction of global warming(Celano 2013; Favoino and Hogg; 2008; Martínez-Blanco et al., 2009; Movahedi Naeini and Cook 2000; Pane et al., 2013, 2016; Scotti et al., 2016; Sánchez et al., 2017; Vázquez and Soto 2017). It also helps to reduce production costs and the negative impacts of agricultural activities through limiting of the use of chemical fertilizers, pesticides and herbicides (Pergola et al., 2017). Additionally, compost can be successfully used in other productive (nursery) and landscape-environmental-hobby activities (green areas, recovery of waste dumps and gardening) (Pergola et al., 2017).

Composts produced from organic wastes has recently been proved to have better quality than synthetic fertilizers (Chowdhury et al., 2015; Onwosi 2017). According to Hermann et al. (2011), composts can replace soil conditioners in support of humus formation, which is a benefit that cannot be achieved by artificial means. Composts improve plant growth and health and also controls different soil-borne phyto-pathogens such as fungi (Traversa et al., 2010). There are three major challenges associated with the composting process, which includes emission of odorous gases (Lou and Nair 2009; Nasini et al., 2016; Blazy et al., 2014), difficulty in defining parameters to determine whether the compost is mature (Lazcano et al., 2008) and production of leachates (Chatterjee et al., 2013). According to Muller et al. (2004), the odour that gets emitted during the composting process could cause discomfort to the public particularly those residing around composting facilities.

2.7.1.2 Compost as an environmental preservation tool

Globally, urbanization as well as the increase in human population has resulted in the generation of a large quantity of wastes (Awasthi et al., 2014). The waste streams used to dispose these materials have led to a number of challenges (environmental, social and economic), especially in developing countries (Awasthi et al., 2014; Sukholthaman and Sharp 2016). Composting is a biochemical as well as heterogeneous process which mineralizes organic matter to CO_2, NH_3, H_2O and incomplete humification, resulting in a stabilized final product, with reduced toxicity and pathogenic organisms (Das et al., 2011). The technique helps reduce organic waste and it in total agreement with the principle of sustainable agriculture (Adbrecht et al., 2011). It provides sanitized and stabilized products that could be utilized as a potential source of organic fertilizers that can be used to amend the soil (Qian et al., 2014). It is a continuous process which reduces organic substances into smaller volumes (Raut et al., 2008). This occurs under natural or controlled conditions and in the end it decomposes organic matter into a useful final product (compost) through microbial activities (Giglotti et al., 2005).

Composting is a widely used technology for transforming organic waste to organic manure (compost), thus recycles mineral nutrients (N, P and K) and it could be utilized for agricultural purposes (Wang et al., 2015). According to Zhang and Sun (2014), green waste is traditionally been incinerated or deposited in landfills, which is an undesirable practice as it produces huge quantities of greenhouse gases and occupies valuable agricultural land. Composting is an environmentally friendly and acceptable way to dispose of and utilize organic wastes (Zhang and Sun 2014). Raut et al. (2008) opined that composting helps in managing large quantities of organic wastes in a sustainable manner; and recycles organic materials into useful products. Composting can also be effective in reducing relatively persistent organic compounds such as veterinary pharmaceuticals (Li et al., 2015).

2.7.2 Potential impact of sustainable agriculture towards achieving food security

Food security refers to the regular availability of adequate world food supplies of basic foodstuffs to withstand a steady expansion of food consumption and to balance fluctuations in production and prices (FAO 2003; Bickel 2000). The final report of the 1996 World Food Summit stated that food security exists when everyone has physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life at all times (FAO 2003). Household food security is achieved when people have access to enough food for an active, healthy life at all times. Individuals who are food secure, do not have to contend with hunger or fear of starvation. The Food and Agriculture Organization of the United Nations classified food security into four principles namely; availability, access, utilization and stability (FAO 2003).

Food access refers to the affordability and allocation of food, as individual and household preferences being met (Bickel 2000; FAO 2003). Access depends on whether the household generates enough income to purchase food at prevailing prices or has sufficient land and other resources to grow its own food (FAO 1997; FAO 2003). The next pillar of food security is food utilization, which refers to the metabolism of food by individuals (Bickel 2000; FAO 2003; FAO 1997). Food security is achieved when food consumed by each individual is safe and the quantity is enough to meet their physiological requirements (FAO 2003; FAO 1997).

Food stability refers to the ability to obtain food over time. At the food production level, natural disasters and droughts result in crop failure and decreased food availability, thus leading to food instability (FAO 1997; FAO 2003). Food availability relates to the supply of food through production, distribution and exchange. Food production is determined by a variety of factors, including land ownership and use, soil management crop selection, crop breeding and management, livestock breeding and management and harvesting (Loring and Gerlach 2009; FAO 2003). The use of land, water and energy to grow food often competes with other uses, which can affect food production. Land used for agriculture can be used for urbanization or lost to desertification, salinization and soil erosion due to unsustainable agricultural practices (Loring and Gerlach 2009).

South Africa's population is growing at almost 2% per year. The population of 49 million in 2009 is expected to grow to 82 million by the year 2035 (Goldblatt 2010). Climate-soil combinations leave only 12% of the country suitable for the production of rain-fed crops, only 3% considered truly fertile land (Goldblatt 2010), thus necessitating the adoption of sustainable agricultural practices in order to ensure food security in the country. Food production or imports must more than double to feed the expanding population, and production needs to increase, using the same or fewer natural resources (Goldblatt 2010).

Challenges to achieving food security include global water crisis, land degradation, climate change, agricultural diseases, food versus fuel, politics and food sovereignty (Kleemann 2012). Risks to food security include population growth, fossil fuel dependence, homogeneity in the global food supply, price setting, land use change and global catastrophic risks (Kleemann 2012; FAO 2003). Sustainable agriculture and food security, therefore stands for maximizing the productivity of the land and improving the well-being of people under the constraint of minimal damage to natural resources (land, water, air and biodiversity) (Pretty 1999; Kleemann, 2012).

2.8 Challenges of subsistence and small-scale farmers in South Africa

The term small-scale is often used interchangeably with smallholder, which refers to farmers that own small plots of land on which they grow crops while relying mostly on family labour (Pearce 2015). Smallholder farmers play a very important role towards global food security and particularly in developing countries, where many vulnerable rural poor communities reside (IFAD 2010). It is estimated that there are about 500 million smallholder farmers globally (FAO 2002), with small-scale farmers in Asia and sub-Saharan Africa producing up to 80% of the food consumed and supporting approximately 2 billion people (FAO 2002). South Africa has a population of about 46 million people with over six million households engaged in smallholder agricultural activities (Stats SA 2012). Socio-economically, most smallholder farmers in South Africa are poor, uneducated and they reside in rural communities with less developed infrastructure, which locates them in the so-called second economy (Jacobs 2008). Commodities crops such as maize, groundnut, dry beans, sugar beans, soybean, bambara groundnut and cowpea can also be grown by smallholder farmers to help alleviate poverty in South Africa (Asiwe 2007).

Majority of the world's population (of poor people) reside in rural areas, with little or no access to productive agricultural lands. Farm size is directly linked with hunger, with approximately 90% of farmers worldwide cultivating on less 2 hectares of land, producing food where it is needed which is predominantly developing countries (Tscharntke et al., 2012). Eighty percent of the poor reside in developing countries, with 50% being smallholder farmers (World Bank 2007). Thus, smallholder farmers rather than large-scale commercial farmers, are the pillars of global food security (Horlings and Marsden 2011; Chappell and LaValle 2011).

Smallholder farmers differ in farm size, their resource distribution between food and cash crops, livestock and off-farm activities, their use of external inputs and hired labour as well as the proportion of food crops sold and household expenditure patterns (DAFF 2012). Even though smallholder production is important for household food security, the productivity of this sector is quite low compared to the commercial farming sector (DAFF 2012). Smallholder farmers in South Africa face various challenges that impede their growth and ability to effectively contribute to food security compared to commercial farmers (DAFF 2012). Some of the constraints they face relate to lack of access to land, poor physical and institutional infrastructure (DAFF 2012). Most of them located in rural areas where there is lack of both physical and institutional infrastructure, thus limiting probability for expansion. Lack of access to proper roads, for example, limits the ability of a farmer to transport their products and also access information. Their infrastructure is very poor, markets for agricultural inputs and outputs are often unavailable and unreliable for smallholder farmers (DAFF 2012), thus resulting in the acquisition of agricultural resources becoming very limited. Lack of assets, information and access to services hinders the participation of smallholder farmers in potentially lucrative markets (DAFF 2012)

Smallholder farmers are hampered by high operation costs and this is largely attributed to poor infrastructure (DAFF 2012). Most of them are inconsistent in terms of production and their lack of bargaining power is also a major challenge. Most smallholder farmers also not consistent in terms of producing products and supplying them to fresh produce markets and agro-processing industries (DAFF 2012) while others are constrained by lack of reliable markets for their products (DAFF 2012). Many of these farmers receive low prices for their products by selling them at local markets which normally doesn't generate enough profits. Lack of human capital has also been found to be a serious challenge for smallholder farmers as most of them are illiterate with poor technological skills, which can be serious obstacles in accessing useful formal institutions that disseminate technological knowledge (DAFF 2012). Lack of improved production knowledge is also a common challenge among smallholder farmers.

2.9 References

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CHAPTER 3: COWPEA (*VIGNA UNGUICULATA* (L.) WALP) RESPONSE TO MOISTURE REGIMES, PHOSPHO-COMPOST APPLICATION AND DIFFERENT SOIL TYPES UNDER TUNNEL HOUSE CONDITIONS

3.1 Abstract

A repeated 2 x 2 x 6 factorial trial was conducted under tunnel house condition at the North-West University experimental farm. The aim of the study was to assess the effect of the application of phospho-compost as a low input agricultural practice on the productivity of grain cowpea. Treatment factors in the trials consisted of six phosphorus (P) fertilizer rates, two soil types and moisture regimes. The P fertilizer treatments consisted of variable phospho-compost rates (0, 10, 20, 40 and 80 t/ha) with 30 kg P/ha rate applied as single super phosphate (SSP 10.5%) included as a standard positive control. The soil types used under tunnel house trial 1 were collected from a smallholder farmer's field in Ventersdorp (Glenrosa) and at the Molelwane North-West University farm (Hutton) while the second trial similarly comprised of Coega and Hutton soil types both collected from the North-West University, Mafikeng Campus. The three factors were combined as treatment and replicated three times to obtain 72 pots per trial, filled with 12 kg of soil. Data collected from both trials included the plant height, stem diameter, number of branches, number of tri-foliate leaves, leaf length, leaf width, leaf area, number of nodules, biomass at harvest, pod parameters and seed yield at harvest.

The different P fertilizer rates exerted significantly ($p \leq 0.05$) influenced all the cowpea growth parameters, with the exception being the leaf length. Soil types used significantly ($p \leq 0.05$) affected the stem diameter and chlorophyll content in the second tunnel house trial. The highest seed yield (12.51 g/pot) and number of pods per plant (8.50) were recorded in the 40 t/ha phospho-compost rate. Cowpea plants grown under the Coega and Glenrosa soil types performed better than those grown in Hutton soil. Application of 30 kg P/ha resulted in the highest mean nodule count (34.3) under tunnel house 1 while moisture stress exerted a depressive effect on cowpea grain yield, fodder weight and number of pods. Although, the moisture deprived plants flowered and formed pods quicker. Application of 40 and 80 t/ha phospho-compost rates significantly increased the residual Bray P content, organic carbon and total N soil content after harvest.

Keywords: Phospho-compost, Moisture stress, P availability, Cowpea, grain yield

3.2 Introduction

The fertility of soils in Sub-Saharan Africa poses one of the biggest challenges to achieving food security and this is prevalent among small-scale farmers, who are generally resource-poor (Masowa et al., 2016). The unsustainable soil management practices of most smallholder farmers often exacerbates this problem (Kutu 2012), leading to further soil degradation. Low-input agricultural practices such as the application of compost, primarily derived from animal manure, can be used as an alternative to inorganic fertilizer. This represents a cheaper way of improving soil fertility while preserving the environment at the same time. The application of compost can also help restore degraded soil and maintain soil quality. Intensive agricultural production often causes the depletion of soil organic matter and nutrients losses. Such soil will, therefore, require nutrient replenishment in order to be productive and often, farmers use fertilizers to supplement the loss of nutrients in the soil.

Smallholder farmers in Sub-Saharan Africa are characterised by low uptake of improved farm inputs. In South Africa, the average application rate of inorganic fertilizer by smallholder farmers is significantly below the recommended levels for the respective agro-ecological regions in the country and are too low and ineffective to sustain crop and soil fertility (Sinyolo and Mudhara 2018). However, the use of inorganic fertilizers alone cannot solve the soil fertility problem that currently persists on many farmlands. Similarly, reports of micronutrients deficiency in inorganic fertilizers abound thereby, necessitating the application of fertilizer sources capable of eliminating micronutrient deficiencies (Adediran et al., 2005). Singh (2002) advocated for the use of organic manures as good sources of food for soil micro-organisms to help increase microbial activity and the conversion of non-available plant nutrients into available form for improved growth, yield and quality of crops. The use of compost as a fertilizer source however, has its drawbacks, such as their low nutrient content, which necessitates large volumes to be used to provide enough nutrients for the growth of crops. Nutrient release is also generally slow to meet crop requirements in a short time, which can cause nutrient deficiencies (Chen 2006). Many resource-poor farmers in South Africa are constrained by the low fertility of South African soils, particularly the common occurrence of P deficiency on their farmlands.

Cowpea (*Vigna unguiculata* (L.) Walp) is an important grain legume and hay crop of many tropical and subtropical regions; its significance is particularly higher in the dry savannah region of West Africa (Fang et al., 2007). The seed or grain is the most important part of the cowpea plant for human consumption. Cowpea plays a critical role in the nutrition and livelihoods of millions of people in the developing world, by serving as a major dietary source of protein that nutritionally complements low-protein cereal and tuber crop staples through various recipes (Ahenkora et al., 1998).

South Africa is predominantly a dryland area with water scarcity problems which raises the need for drought tolerant crops that can survive periods of water stress. Compared to other legumes, cowpea has good adaptation to high temperatures and resistance to drought stress (Hall 2004). It has a very good water-use efficiency that represents an important trait for dryland farming. Drought stress is one of the most adverse factors of plant growth and productivity; considered as a huge barrier towards sustainable crop production (Anjum et al., 2011). According to El Naim (2003), water stress significantly affect stomatal closure, photosynthesis, decreases plant growth, reduces leaf area , leaf senescence and reduction in cell development; and the ultimate undesirable effect of crop yields and quality parameters. Drought adaptation in cowpea relates to minimized water losses by the control of stomatal aperture (De Carvalho et al., 1998). The ability of cowpea to be able to thrive under drier conditions, because of its water use efficiency, provides an economic advantage, particularly with water stress being a major problem in agricultural production. Two tunnel house trials were set up to evaluate the response of cowpea to the application of phospho-compost on two soil types, with varying moisture levels. It was hypothesized that the application of phospho-compost will (i) promote improved cowpea growth and grain yield under moisture stress conditions, (ii) increase availability of soil P and mitigate the negative effect of P deficiency under moisture stress conditions and (iii) the productivity of cowpea will not be negatively affected by dryland and greenhouse conditions.

3.3 Materials and methods

3.3.2 Description of the study site

Two related tunnel house trials were planted at the North-West University (NWU) Experimental farm (Molelwane), Mafikeng. The farm is located near Moshawane Village, Mafikeng, North-West Province in a savannah area with semi-arid climate. The tunnel house used was located 25° 47" 404'S, 025° 37" 292'E, 1298.08 metres above sea level.

3.3.2 Production and chemical characterization of compost

Compost was prepared under anaerobic conditions for a period of approximately four months. The preparation of P-enriched compost was done prior to the initiation of the tunnel house and field trials as it was used as fertilizer for the two tunnel house trials and one field trial. The organic material used to prepare compost included animal manure collected from Molelwane experimental farm of NWU, Mafikeng Campus. The raw materials used for the production of phospho-compost included cattle, sheep and poultry manure collected from the kraal from the Molelwane experimental farm of NWU while sawdust was purchased from a local feed store (Mimosa Chicks) in Mafikeng town. Phosphorous enrichment of the compost was through the addition of ground phosphate rock (GPR) purchased from Foskor mining company, Phalaborwa. Each compost heap contained a mixture of manure: GPR mix ratio of 8:2 (w/w) consisting of 450 kg of cattle manure, 150 kg of sheep manure, 150 kg of poultry manure and 50 kg of sawdust mixed with 200 kg GPR. Table 1 shows a detailed chemical composition of the manure and the resulting phospho-compost used in this study. Preparation of the phospho-compost was through aerobic thermophilic process in a heap on bare ground laid by 100 nm thick polyethylene sheet under shed to prevent loss of leachates during the co-composting process. Regular turning of the compost with the addition of moderate water was done at 2-week intervals to provide proper aeration.

The moisture content of the compost was below field capacity during the composting period in order not to slow down microbial activities. The composting process lasted about 16 weeks to allow for full maturity or compost curing. Temperature readings from the phospho-compost heap at different parts and depths were taken prior to turning the compost. Sampling of the compost at maturity was for detailed chemical characterization. The maturity indices and chemical characteristics of the compost assessed included organic carbon content, total and inorganic N following standard laboratory procedures. The chemical attributes of the compost upon maturation are shown in Table 3.1 below.

Table 3.1: Chemical attributes of the raw materials used for the preparation of phospho-compost and the resulting compost

Description	Total N mg/g	mg/kg N-NO_3	N-NH_4	Bray-P	Exch K	g/kg C	P	K	Ca	Mg	Na	S	Al	mg/kg Mn	Fe	Cu	Zn
S-manure	1.96	nd	nd	nd	nd	302	9.89	2.43	91.31	7.09	4.63	62.97	24.45	578	578	51.2	11.2
C-manure	2.23	nd	nd	nd	nd	349	8.56	77.54	128.98	16.29	18.87	76.90	2.87	181	214	14	3.2
P-manure	2.48	nd	nd	nd	nd	285	14.1	39.2	133.72	12.93	16.9	68.84	4.85	163	359	25.7	4.88
P-compost	3.14	1280	13.7	2261	8438	323	68.37	83.65	700.98	20.11	14.35	56.55	5.96	290	436	28.4	6.4

S manure = Sheep manure, C manure = Cattle manure, P-manure = poultry manure, P-compost = Phospho-compost, nd implies not determined

3.3.3 Description of the tunnel house trials

The study consisted of two separate 2×2×6 factorials experiments fitted into a RCBD. Each of the tunnel house trials consisted of three factors as follows: co-composted GPR-manure mixture as P fertilizer sources; 2 moisture levels (irrigation); and 2 soil types. The two soil types for each experiment consisted of varied clay, organic carbon and pH content collected. The soils used for the first tunnel house trial were from the Molelwane experimental farm of the North-West University, with 14% clay content and classified Hutton (Materechera and Gaobope 2007), while the second soil was a red apedal Glenrosa with 16% clay content obtained from a smallholder farmer's field in Ventersdorp. In the second tunnel house trial, treatments were the same, except the two soil types used were light yellow, calcic with hard carbonate B classified as Coega soil with 18% clay content, was obtained from the North-West University, Mafikeng Campus (behind the Animal Health Clinic) and the second soil type was from the Molelwane experimental farm of the North-West University, with 14% clay content and classified Hutton (Materechera and Gaobope 2007). The soils represented surface soil samples taken from 0-20 cm depth. Hence, both tunnel house trials consisted of five P-enriched compost rates (0, 10, 20, 40, and 80 t/ha), inorganic P-fertilizer in the form of Single Superphosphate 10:5 (SSP) applied at a rate of 30kg/ha was included to the varied compost rates as positive control. Introduction of moisture stress was at 5 weeks after planting prior to floral initiation. The condition of unstressed plant entailed adequate daily provision of moisture for irrigation, using 600 ml while moisture-stressed plants received no irrigation for a period sometimes longer than three (3) days, depending on the weather condition and with plants showing visible signs of loss of turgidity through wilting. At such point, there was the addition of only 300 ml of water.

The three treatment factors which were 2 soil types, 2 moisture regimes and 6 fertilizer rates were combined (2 x 2 x 6) to give 24 treatment combinations, these 24 treatment combinations were replicated 3 times to obtain a total of 72 pots. Four seeds of white cowpea variety (IT00K-1217) were sown per pot and after the seeds were sown, the pots were irrigated to keep the soil water at near field capacity in order to allow the seeds to germinate. Thorough mixing of added P-rich compost to the soil-filled pot based on individual application rates done prior to seed sowing and thereafter transferred into clearly labelled pots based on the specified treatments. Similarly, 30 kg/ha inorganic P fertilizer (SSP 10.5% P) amounting to 18 g pot^{-1} was weighed and added to well-labelled soil-filled pot and thoroughly mixed. Imposition of soil moisture treatments was at 5 weeks after planting

(WAP). The characteristics of the soils used for the tunnel house trials are shown below in Table 3.2.

Table 3.2: Physical and chemical characteristics of the soil types used for the two tunnel house trials

Soil characteristics	**Molelwane (Hutton)**	**Ventersdorp (Glenrosa)**	**NWU Campus (Coega)**
Sand (%)	74	52	50
Silt (%)	12	32	32
Clay (%)	14	16	18
Textural class	Sandy loam	Loam	Clay loam
pH (H_2O)	7.36	7.66	7.48
pH (KCl)	6.06	6.77	6.68
Electrical conductivity (μ_{s})	78.6	64.3	52.5
Total N (mg/g)	3.29	2.43	3.84
Total C (mg/g)	1.82	3.91	2.73
Total S (mg/g)	0.01	0.04	0.01
Bray-1 P (mg/kg)	75	80	66
K (mg/kg)	168	235	221

3.3.4 Data collection from the tunnel house

Data collection from the tunnel house trials was done at vegetative, flowering and physiological maturity stages. Cowpea growth parameters were measured 5 WAP prior to moisture stress, and subsequently, at 7 and 10 WAP after the imposition of moisture stress. The measured growth parameters included plant height measured using 5-m steel metre tape, stem diameter using a Vernier caliper, the number of branches and the number of tri-foliate leaves per plant by counting. Others included leaf length measured from the petiole to the tip of the trifoliate leaf, and leaf width measured from the two points where the leaf was the broadest. Healthy and fully developed trifoliate leaves were chosen for the measurement of both leaf length and breadth using a steel metre tape and expressed in centimetres. The readings obtained for the leaf area were estimated using the equation (L* W*2.325) with L representing the length of the selected leaf and W being the width of the leaf, the equation was obtained from Osei-Yeboah et al, (1983). Phenological parameters included the number of days to 100% flowering and the number of days to 100% pod formation. The nodule count, nodule weight, Plant biomass, pod characteristics (e.g. number of pods per plant, pod length, pod weight, number of seeds per pod) and average seed weight per pot (i.e. grain yield) were all recorded at harvest. Post-harvest soil and plant analyses were done after the termination of the trials.

3.3.5 Description of laboratory analyses on soil and plant tissue samples

Post-harvest sampling for soil analyses of the two tunnel house trials was after the termination of the trials. Air drying and sieving (2 mm diameter mesh) of soil samples taken from the trials was done, while plant oven drying of plant tissue samples to constant weight was at 65°C and, thereafter, milled and used for detailed chemical analyses. Measurement of soil pH and electrical conductivity (EC) in soil/water suspension (a 1:2.5) and read on a PHS-3BW pH metre and a DDS-11AW Benchtop conductivity meter, respectively. Measurement for soil available P was done using the Bray-1 procedure and read on a SP-UV 300SRB Spectrophotometer. The determination of total carbon, N and Sulphur (S) were done using the LECO Trumac CNS analyser.

3.3.6 Statistical analyses

Growth and yield data (generated from the trial) was subjected to statistical Analysis of Variance (ANOVA) procedure using Statistix 10.0. The Least Significant Difference (LSD) test was then performed at $p \leq 0.05$ to establish significant difference between treatment means. Linear correlation analysis was run between selected growth and yield attributes.

3.4 Results

3.4.1 Treatment factors and their interaction effects on measured growth parameters in trial 1

Table 3.3 shows the ANOVA of cowpea growth parameters as influenced by different treatment factors. Results of growth parameters measured prior to moisture stress imposition at 5 weeks after planting (WAP) showed that the different fertilizer rates had a significant ($p \leq 0.001$) influence on plant height, number of branches, chlorophyll content and the width of leaves. The soil types used similarly exerted a significant ($p \leq 0.05$) influence on plant height, chlorophyll content, leaf length, leaf width and the leaf area while fertilizer rates had no significant ($p \leq 0.05$) effect on the number of trifoliate leaves, leaf length and subsequently, the leaf area. Results also showed that the fertilizer rate and soil type interaction did not significantly ($p \leq 0.05$) influence all the selected cowpea growth parameters. Table 3.4 shows that at 5 WAP pots fertilized with inorganic P produced the tallest plants (32.92cm), highest number of leaves (5.13), number of branches (0.33), chlorophyll content (97.21 CCI) and cowpea leaf area (109.96 cm^2) while application of the 80 t/ha phospho-compost rate performed poorest on these measured growth parameters. The cowpea leaf area measured from phospho-compost rates of 10 t/ha and beyond were statistically similar. The performance of cowpea was generally better in Glenrosa soil with recorded tallest plants (32 cm) and highest leaf length (9.07 cm), leaf width (5.29 cm) and leaf area (114.52 cm^2).

Table 3.3: Mean squares for the growth parameters of cowpea measured in tunnel house trial 1

Sources of variation	Plant height	No. of branches	No. of trifoliate leaves	Chlorophyll content	Leaf length	Leaf width	Leaf area
			Prior to moisture stress imposition at 5 Weeks After Planting (WAP)				
Fertilizer rates (FR)	98.10***	0.34ns	4.08**	1621.4ns	1.89ns	1.47*	1208.47ns
Soil type (ST)	32.51*	0.52ns	1.33ns	10791.0*	9.54*	7.68*	8850.36*
FR x ST	12.79ns	0.05ns	0.35ns	369.7ns	1.77ns	0.91ns	1114.97ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.4: Effects of fertilizer rate and soil type on measured cowpea growth parameters from tunnel house trial 1 at 5 WAP

Treatments	Plant height (cm)	No. of branches	No. of trifoliate leaves	Chlorophyll content (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
P application rates (t ha^{-1})							
0	32.13abc	0.17ab	5.08a	80.28ab	8.85a	5.01a	105.92a
10	32.66ab	0.13ab	4.88a	89.63ab	8.69a	4.94ab	101.73a
20	31.10bc	0.21ab	4.92a	83.71ab	8.47a	4.85ab	98.01a
40	30.86c	0.04b	4.72a	82.72ab	8.87a	4.79ab	100.75a
80	27.41d	0.02b	4.00b	73.17b	8.13a	4.51b	89.26a
Inorganic P[#!]	32.92a	0.33a	5.13a	97.21a	8.79a	5.25a	109.96a
Soil types							
Glenrosa	32.00a	0.25a	4.95a	99.45a	9.07a	5.29a	114.52a
Hutton	30.36b	0.04a	4.62a	69.46b	8.18b	4.49b	87.36b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 3.5 shows the ANOVA of cowpea growth parameters as influenced by different treatment factors. The results of growth parameters measured after imposition of moisture stress at 7 weeks after planting (WAP) showed that the fertilizer rate and soil type had a significant ($p \leq 0.001$) effect on leaf length, leaf width and leaf area while none of the treatment interactions effect had a significant ($p \leq 0.05$) effect on the number of branches and trifoliate leaves. Moisture stress had a significant effect on all measured growth variables, with the exception of plant height while the interaction between fertilizer rate and moisture had a significant ($p \leq 0.05$) effect on the chlorophyll content of cowpea leaves at 7 WAP. However, all measured parameters at 10 WAP were significantly affected by imposition of moisture stress while leaf chlorophyll content, leaf length and width were affected significantly ($p \leq 0.05$) by fertilizer rates as well as the interaction between fertilizer rate and soil types. Soil type and moisture regime interaction also exerted a significant ($p \leq 0.05$) influence on plant height and chlorophyll content. The 3-way interaction between fertilizer rate, soil type and moisture regime significantly ($p \leq 0.05$) influenced the cowpea leaf length and leaf area at 7 WAP.

Table 3.6 shows that pots fertilized with inorganic P produced the tallest plants (42.32 cm), highest number of branches (3.11), chlorophyll content (66.22 CCI) after moisture stress imposition at 7 WAP. However, the 80t/ha phospho-compost rate performed poorest at 7 WAP. The longest leaves (11.33 cm) and widest leaves were (7.02cm) were from pots supplied with the 80 t/ha fertilizer rate, the highest leaf area (186.18 cm^2) was recorded in pots supplied with the 40 t/ha fertilizer rate while the shortest leaves (9.03 cm) and lowest leaf area were from unfertilized pots. The Glenrosa soil type gave a better cowpea performance on all measured growth parameters, including plant height, number of branches, number of trifoliate leaves, chlorophyll content, leaf length, leaf width and the leaf area at 7 WAP. However, the highest number (2.53) of branches recorded in pots were not subjected to any moisture stress. Similarly, the highest number of leaves (15.07) recorded was in pots that were not subjected to moisture stress. Pots that were supplied with full irrigation had the highest Chlorophyll content (57.43 CCI), leaf length (10.57 cm), leaf width (6.58 cm) and the highest leaf area (164.06 cm^2).

Table 3.5: ANOVA of measured cowpea growth parameters from tunnel house trial 1 after moisture stress imposition

Sources of variation	Plant height (cm)	No. of branches	No. of trifoliate leaves	Chlorophyll content (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
After moisture stress imposition at 7 Weeks After Planting (WAP)							
Fertilizer rate (FR)	57.68*	4.99ns	177.97ns	4569.3***	11.05***	5.36***	9764.3***
Soil type (ST)	168.32*	17.64*	4.46ns	10786.2***	15.13**	4.80*	10292.6**
Moisture regime (MR)	91.10ns	10.47*	938.88*	33105.1***	8.57*	5.21*	8252.1*
FR x ST	33.02ns	1.51ns	144.73ns	667.1ns	6.85***	3.10***	5313.0***
FR x MR	26.38ns	1.14ns	188.15ns	1322.0*	1.34ns	0.36ns	626.6ns
ST x MR	115.93*	0.03ns	193.25ns	1419.6*	0.62ns	0.26ns	70.4ns
FR x ST x MR	51.01ns	1.79ns	170.13ns	97.5 ns	2.83*	0.91ns	1797.3*
After moisture stress imposition at 10 Weeks After Planting (WAP)							
Fertilizer rate (FR)	53.64*	8.20*	14.07ns	1216.57*	5.61*	3.54**	4260*
Soil type (ST)	1.37ns	12.07*	10.08ns	1274.67*	1.53ns	0.46ns	793ns
Moisture regime (MR)	767.70***	63.45***	1155.76***	5941.29***	75.61***	40.25***	62965***
FR x ST	25.18ns	2.67ns	2.12ns	812.20*	4.84*	4.21**	5088**
FR x MR	61.86ns	5.01ns	8.52ns	2450.55*	0.40ns	0.18ns	143ns
ST x MR	20.05ns	1.38ns	5.83ns	120.59ns	1.76ns	0.73ns	901ns

*, ** & *** implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.6: Effects of fertilizer rate, soil type and moisture regime on growth parameters of cowpea collected after moisture stress imposition (7 WAP) from tunnel house trial 1

Treatment factors	Plant height (cm)	No. branches	No. of trifoliate leaves	Chlorophyll content (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
P application rates (t ha^{-1})							
0	37.51b	2.08b	9.83b	24.58c	9.03d	5.53c	119.12d
10	39.78ab	1.87b	10.46b	31.24bc	9.95c	6.14b	144.62c
20	40.26ab	2.48ab	17.52a	39.48b	10.18c	6.24b	151.01c
40	40.92a	2.08b	11.33ab	35.83b	10.44bc	6.40b	157.78bc
80	39.58ab	1.68b	10.83b	43.07b	11.33a	7.02a	186.18a
Inorganic P$^{\#!}$	42.32a	3.11a	13.08ab	66.22a	10.82ab	6.86a	173.63ab
Soil types							
Glenrosa	42.33a	2.95a	12.52a	58.21a	10.97a	6.75a	173.11a
Hutton	37.79b	1.48b	11.78a	21.93b	9.61b	5.98b	137.67b
Moisture regime							
No Stress	40.97a	2.53a	15.07a	57.43a	10.57a	6.58a	164.06a
Stress	39.15a	1.91b	9.23b	22.71b	10.01b	6.15b	146.72b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 3.7 shows that at 10 weeks after planting (WAP), pots fertilized with inorganic P produced the tallest plants (42.96 cm), highest number of branches (4.01), highest number of leaves (10.72), highest chlorophyll content (39.90 CCI), widest leaves (6.24 cm) and the highest cowpea leaf area (142.48 cm^2). The number of cowpea leaves measured from all the fertilizer rates were statistically similar. The performance of cowpea was generally better in Glenrosa soil with recorded tallest plants (40.04 cm), highest number of branches (3.44), chlorophyll content (32.92 CCI), leaf length (9.45 cm), leaf width (5.86 cm) and leaf area (131.82 cm). However, the plant height, number of trifoliate leaves, leaf length and width, and leaf area measured from the two soil types were statistically similar. The results also revealed that cowpea in pots not subjected to water stress, had the tallest plants (42.45 cm), highest number of branches (3.59), number of leaves (13.08) Chlorophyll content (34.06 CCI), leaf length (10.06 cm), leaf width (6.34 cm) and leaf area (150.63 cm^2).

Table 3.7: Effects of fertilizer rate, soil type and moisture regime on growth parameters of cowpea collected after moisture stress imposition 10 WAP from tunnel house trial 1

Treatment factors	Plant height (cm)	No. of branches	No. of trifoliate leaves	Chlorophyll (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm2)
P application rates (t ha^{-1})							
0	37.58b	2.39b	9.14a	19.99b	8.28b	5.07b	102.81b
10	40.66ab	2.55b	9.83a	21.27b	9.26ab	5.76ab	125.50ab
20	40.09ab	3.09ab	10.51a	28.49ab	9.12ab	5.48ab	120.92ab
40	40.84ab	2.90ab	10.69a	31.13ab	9.79a	6.07a	140.59a
80	37.89ab	2.10b	8.37a	19.99b	9.39ab	5.83ab	129.64ab
Inorganic P[#!]	42.96a	4.01a	10.72a	39.90a	9.61a	6.24a	142.48a
Soil types							
Glenrosa	40.04a	3.44a	10.42a	32.92a	9.45a	5.86a	131.82a
Hutton	39.64a	2.24b	9.33a	20.67b	9.03a	5.63a	122.16a
Moisture regime							
No stress	42.45a	3.59a	13.08a	34.06a	10.06a	6.34a	150.63a
Stress	37.23b	2.09b	6.67b	19.53b	8.42b	5.14b	103.35b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

3.4.2 Treatment factors and their interaction effects on selected cowpea growth parameters measured in tunnel house trial 2

Table 3.8 shows the ANOVA of cowpea growth parameters as influenced by different treatment factors. The results of growth parameters measured after moisture stress imposition showed that the different fertilizer rates significantly ($p \leq 0.0001$) influenced the plant height, stem diameter, number of branches and leaves, chlorophyll content and leaf width while soil types exerted significant ($p \leq 0.001$) influence on the Chlorophyll content. Additionally, stem diameter was also significantly ($p \leq 0.05$) influenced by the soil type. The results also showed that moisture regime significantly ($p \leq 0.001$) influenced the plant height, stem diameter, number of branches and the number of leaves. The sampling date significantly ($p \leq 0.0001$) influenced the stem diameter, number of branches, number of leaves and the chlorophyll content of cowpea plants

The interaction between the fertilizer rate and soil type had a significant ($p \leq 0.001$) influence on plant height, stem diameter, number of branches, number of leaves, chlorophyll content and leaf width. The interaction between fertilizer rate and moisture regime had a significant ($p \leq 0.0001$) influence only on the plant height of cowpea plants while the sampling date, moisture regime and sampling date interaction exerted a significant ($p \leq 0.05$) influence on the height of cowpea plants. The three-way interaction between the fertilizer rate, soil type and moisture regime significantly ($p \leq 0.05$) influenced the chlorophyll content while all other treatment interactions did not have a significant ($p \leq 0.05$) effect on all measured growth parameters. The results also showed that the length of cowpea leaves was not significantly ($p \leq 0.05$) influenced by all the treatment factors while leaf area was significant ($p \leq 0.05$) only for the different fertilizer rates and the interaction between fertilizer rate and soil type.

Table 3.8: ANOVA of measured cowpea growth parameters as affected by treatment factors and their interactions from second tunnel house trial

Sources of variation	**Plant height (cm)**	**Stem diameter (cm)**	**No. of branches**	**No. of trifoliate leaves**	**Chlorophyll (CCI)**	**Leaf length (cm)**	**Leaf width (cm)**	**Leaf area (cm^2)**
Fertilizer rate (FR)	904.38***	0.23***	29.92***	121.96***	2271.6 *	103.67ns	35.56***	68588.8*
Soil type (St)	33.53ns	0.08*	5.08ns	27.97ns	12840.8**	15.41ns	0.54ns	9492.2ns
Moisture regime (M)	710.37***	0.42***	70.22***	399.81***	591.3 ns	79.61ns	3.17*	39448.3ns
Sampling date (Sd)	162.06*	0.38***	96.42***	375.64***	32258.7***	33.93ns	0.20ns	9334.5ns
FR*St	699.72***	0.14***	29.63***	125.95***	7944.4***	110.16ns	14.23***	55582.2*
FR*M	174.44***	0.02ns	0.98ns	4.62ns	1270.0 ns	58.60ns	1.30ns	23868.7ns
FR*Sd	1.63ns	0.01ns	3.31ns	16.40ns	822.7 ns	50.46ns	0.19ns	16838.3ns
St*M	16.83ns	0.00ns	14.92*	48.45ns	271.9 ns	59.99ns	4.77*	37372.8ns
St*Sd	2.43ns	0.00ns	2.37ns	30.73ns	304.3 ns	34.05ns	0.00ns	10861.9ns
M*Sd	30.15ns	0.03ns	1.27ns	36.11ns	169.0 ns	49.85ns	0.00ns	14457.7ns
FR*St*M	36.43ns	0.01ns	1.90ns	8.37ns	2648.4*	42.60ns	0.16ns	15198.3ns
FR*St*Sd	1.32ns	0.00ns	3.21ns	8.14ns	247.9 ns	41.56ns	0.02ns	13538.5ns
FR*M*Sd	2.85ns	0.01ns	1.64ns	7.71ns	753.0 ns	48.44ns	0.15ns	15136.6ns
St*M*Sd	6.08ns	0.01ns	1.08ns	0.10ns	51.6 ns	48.17ns	0.06ns	14169.4ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.9 shows that between 7 and 10 weeks after planting (WAP), pots fertilized with inorganic P, produced the tallest plants (49.85 cm), the highest stem diameters (0.76 cm), number of branches (4.96), number of trifoliate leaves (15.65), chlorophyll content (74.75 CCI) and leaf width while unfertilized pots performed poorest on these measured growth parameters. However, cowpea had the highest leaf width (13.40 cm) and the highest leaf area (205.78 cm^2) in pots supplied with the 80 t/ha fertilizer rate. The performance of cowpea was generally better in Coega soil producing the widest stems (0.70 cm) and highest chlorophyll content (74.75 CCI). The results also showed that the performance of cowpea was generally better in pots not subjected to any moisture stress with recorded tallest plants (44.64 cm), widest stems (0.70 cm), highest number of branches (4.14) and leaf width (6.32 cm). Different sampling dates also had significant effects on the growth parameters of cowpea. The performance of cowpea was generally better 10 WAP with recorded tallest plants (43.77 cm), widest stems (0.72 cm), highest number of branches (4.22), number of leaves (14.13) compared to when growth parameters were measured 7 WAP. There were no significant differences in leaf length, leaf width and leaf area between the two sampling dates.

Table 3.9: Effects of fertilizer rate, soil type, moisture regime and the sampling date on selected growth parameters collected at 7 and 10 weeks after planting from tunnel house trial 2

Treatment factors	Plant height (cm)	Stem diameter (cm)	No. of branches	No. of trifoliate leaves	Chlorophyll (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
Fertilizer rate (t ha^{-1})								
0	35.67d	0.54c	2.27c	10.50c	55.28b	8.77b	4.51c	97.26b
10	43.72b	0.64b	3.88ab	13.71ab	55.71ab	10.94ab	6.21b	159.99ab
20	43.72b	0.66b	3.96ab	13.04ab	63.77ab	11.38ab	6.45b	172.73ab
40	44.73b	0.70ab	3.79ab	13.10ab	67.25ab	11.29ab	6.59b	174.46ab
80	40.25c	0.69ab	3.08bc	11.67bc	67.20ab	13.40a	6.26b	205.78a
Inorganic P#!	49.85a	0.76a	4.96a	15.65a	74.75a	11.78ab	7.21a	200.46a
Type of soil								
Coega	43.70a	0.70a	3.90a	13.59a	77.81a	11.74a	6.30a	180.33a
Hutton	42.28a	0.63b	3.35a	12.30a	50.18b	10.78a	6.12a	156.57a
Moisture regime								
No stress	44.64a	0.70a	4.14a	14.18a	65.50a	11.81a	6.32a	180.73a
Stressed	41.34b	0.62b	3.10b	12.30a	62.43a	10.71a	6.10b	156.17a
Sampling date								
7 WAP	42.21b	0.63 b	3.02b	11.76b	74.99a	10.90a	6.24a	162.53a
10 WAP	43.77a	0.72a	4.22a	14.13a	53.00b	11.62a	6.18a	174.36a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

3.4.3 Treatment factors and their interaction effects on selected cowpea yield and yield attributes from tunnel house trial 1

Table 3.10 shows the ANOVA of cowpea yield and yield attributes as influenced by different treatment factors. The results of cowpea yield and yield attributes measured showed that different fertilizer rates significantly ($p \leq 0.05$) influenced nodule count and nodule weight of cowpea plants. The soil types used did not significantly ($p \leq 0.05$) influence all the selected cowpea yield and yield attributes. The results also showed that moisture regimes used exerted a significant ($p \leq 0.05$) influence on the number of pods, pod length, seed weight per pod and seed yield per pot. Additionally, moisture regimes significantly ($p \leq 0.001$) influenced the pod weight, number of seeds per pod and fodder weight per pot. The results also showed that the fertilizer rates and soil types interaction significantly ($p \leq 0.05$) influenced nodule count, number of seeds per pod, seed weight per pod and fodder weight per pot while the soil type and moisture regime interaction significantly ($p \leq 0.05$) influenced pod length, pod weight and seed weight per pod. However, the fertilizer rate and moisture regime interaction did not significantly ($p \leq 0.05$) influence all the measured cowpea yield attributes and seed yield.

Table 3.11 shows that at harvest, pots fertilized with inorganic P produced the highest number of nodule (34.30), nodule weight (3.53 g) and fodder weight per pot (13.95 g) while the 80 t/ha performed poorest on these three parameters. The number of pods, pod length, pod weight, number of seeds per pod, seed weight per pod and seed yield per pot were statistically similar for all the fertilizer rates used. Similarly, no significant differences in cowpea grain yield measured between the two soil types were observed. The performance of cowpea was generally better in pots not subjected to moisture stress with a recorded higher number of pods (6.78), pod length (14.57 cm), pod weight (1.54 g), number of seeds per pod (7.13), seed weight per pod (1.03 g), seed yield per pot (6.13 g) and fodder weight per pot (15.16 g).

Table 3.10: ANOVA of measured nodule parameters, pod characteristics, fodder weight and cowpea seed yield from tunnel house trial 1

Sources of variation	**Nodule count**	**Nodule weight (g)**	**No. of pods**	**Pod length (cm)**	**Pod weight (g)**	**No. seeds pod^{-1}**	**Seed weight pod^{-1} (g)**	**Seed yield pot^{-1} (g)**	**Fodder weight pot^{-1} (g)**
Fertilizer rate (FR)	954.67*	18.99*	1.14ns	3.42ns	0.07ns	3.78ns	0.06ns	3.42ns	64.02ns
Soil type (ST)	141.78ns	13.10ns	16.58ns	2.51ns	0.14ns	0.02ns	0.06ns	5.66ns	35.50ns
Moisture regime (M)	332.50ns	11.12ns	57.30*	24.82*	2.16**	37.28**	0.92*	85.99*	1280.57**
FR*ST	1172.37*	21.36ns	6.37ns	2.76ns	0.22ns	5.71*	0.23*	14.35ns	84.19*
FR*M	124.37ns	10.55ns	3.23ns	0.96ns	0.08ns	2.12ns	0.06ns	4.12ns	4.17ns
ST* M	237.54ns	8.62ns	3.75ns	9.89*	1.20*	3.07ns	0.87*	22.60ns	50.60ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.11: Effects of various treatment factors on cowpea nodules, yield attributes and fodder weight from tunnel house trial 1

Treatment factors	**Nodule count**	**Nodule weight (g)**	**No. of pods**	**Pod length (cm)**	**Pod weight (g)**	**No. seeds pod^{-1}**	**Seed weight pod^{-1} (g)**	**Seed yield (g)**	**Fodder weight (g)**
Fertilizer rate (t ha^{-1})									
0	15.38b	2.15a	5.16a	13.47a	1.22a	5.60a	0.79a	3.90a	9.95b
10	16.06ab	2.75a	5.56a	12.61a	1.18a	5.37a	0.79a	3.97a	12.63ab
20	0.26c	0.40b	5.48a	13.52a	1.21a	5.34a	0.77a	3.88a	11.75ab
40	0.47c	0.74b	6.17a	14.41a	1.40a	6.98a	0.88a	5.29a	13.93a
80	0.23c	0.33b	5.18a	15.18a	1.34a	7.06a	1.01a	5.69a	10.06b
Inorganic P[#!]	34.30a	3.53a	5.23a	13.05a	1.39a	6.11a	0.96a	4.47a	13.95a
Soil type									
Glenrosa	12.07a	2.05a	6.63a	14.16a	1.40a	6.12a	0.93a	5.21a	13.08a
Hutton	5.35a	0.10a	4.23a	13.25a	1.19a	6.04a	0.79a	3.85a	11.08a
Moisture regime									
No Stress	14.05a	2.01a	6.78a	14.57a	1.54a	7.13a	1.03a	6.13a	15.16a
Stress	3.37a	0.05a	4.16b	12.85b	1.03b	5.02b	0.70b	2.94b	9.01b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

3.4.4 Treatment factors and their interaction effects on nodule characteristics, yield and yield attributes from tunnel house trial 2

Table 3.12 shows the ANOVA of cowpea yield and yield attributes as influenced by different treatment factors. The results showed that different fertilizer rates significantly ($p<0.05$) influenced the number of days to flowering, number of pods, pod length, fodder weight and seed yield, nodule count was affected significantly ($p\leq0.001$) by the different fertilizer rates. Soil types used significantly ($p\leq0.05$) influenced the fodder weight of cowpea plants. The results of ANOVA also showed that moisture significantly ($p<0.05$) influenced the measured cowpea yield and yield attributes, except for phenological parameters such as the number of days to 100% flowering, number of days to 100% pod formation and the nodule count. The results also showed that the fertilizer rate and soil type interaction significantly ($p<0.05$) influenced the number of days to 100% pod formation, number of pods, pod length, number of seeds per pod, seed weight per pod, and seed yield per pot. The interaction was also exerted significant ($p\leq0.001$) influence on the nodule count, pod weight and fodder per pot. The interaction between soil type and moisture regime significantly ($p<0.05$) influenced the pod length, pod weight and seed weight per pod, however, interaction between fertilizer rate and moisture regime significant ($p<0.05$) influenced only the nodule count of cowpea plants.

Table 3.12: Mean sum of square for phenological parameters, nodule count, fodder weight, pod characteristics and cowpea seed yield from tunnel house trial 2

Sources of variation	**Days to 100% flowering**	**Days to 100% pod formation**	**Nodule count**	**Number of pods**	**Pod length**	**Pod weight**	**No. seeds pod^{-1}**	**Seed weight pod^{-1}**	**Seed yield (g)**	**Fodder weight (g)**
Fertilizer rate (FR)	75.86*	812.93ns	192.65***	43.80*	46.30*	0.68ns	7.84ns	0.42ns	87.69*	44.13*
Soil type (ST)	18.24ns	85.96ns	3.07ns	11.84ns	6.17ns	0.11ns	26.19ns	0.04ns	10.87ns	86.48*
Moisture regime (M)	12.89ns	698.82ns	11.85ns	88.85*	87.44*	3.23*	93.70*	1.78*	199.55*	122.19*
FR*ST	40.45ns	1315.45*	212.65**	44.01*	85.45*	2.04**	34.10*	1.20*	88.53*	74.94**
FR*M	30.42ns	371.67ns	83.99*	16.08ns	6.70ns	0.13ns	14.34ns	0.08ns	25.25ns	19.63ns
ST*M	36.26ns	722.96ns	16.67ns	0.25ns	78.56*	1.80*	8.26ns	1.22*	7.67ns	33.96ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.13 shows that different fertilizer rates had significant effects on selected yield and yield attributes. The results showed that the application of 10 t/ha phospho-compost rate produced the highest nodule count (9.58) and fodder weight (11.78 g) while the application of 40 t/ha phospho-compost rate produced the highest seed yield (12.51 g/pot). The number of days to 100% pod formation, counted from all the phospho-compost rates, were statistically similar. There were no significant differences in the number of days to 100% flowering, number of days to 100% pod formation, nodule count, fodder weight and seed yield between the two soil types used. The performance of cowpea was generally better in pots not subjected to moisture stress with recorded highest fodder weight (10.98 g) and seed yield (9.76 g).

Table 3.13: Effects of treatment factors on phenological parameters, nodule count, fodder weight and cowpea seed yield from tunnel house trial 2

Treatment factors	Days to 100% flowering	Days 100% pod formation	Nodule count	Fodder weight (g)	Seed yield (g)
Fertilizer rate (t ha^{-1})					
0	51.42ab	53.58a	5.38ab	8.16b	4.93b
10	50.42ab	56.75a	9.58a	11.78a	7.56ab
20	47.75b	51.00a	6.04ab	9.42ab	8.74ab
40	48.42ab	49.83a	2.67b	10.60ab	12.51a
80	54.50a	57.46a	1.63b	9.23ab	5.65b
Inorganic P[#!]	48.39ab	50.24a	6.42ab	11.16ab	8.80ab
Soil type					
Coega	49.18a	54.42a	5.58a	11.13a	8.82a
Hutton	51.12a	52.20a	4.99a	8.99a	7.25a
Moisture regime					
No stress	50.58a	55.56a	5.58a	10.98a	9.76a
Stress	48.71a	49.07a	4.97a	9.14b	6.30b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 3.14 shows that cowpea pod parameters were generally better in pots fertilized with the 40 t/ha phosphor-compost rate, with the highest number of pods (8.50) and pod lengths (14.94 cm) recorded while the measured cowpea pod parameters were poor in unfertilized pots. The cowpea pod weight, number of seeds per pod and the seed weight per pod measured from all the fertilizer rates used were statistically similar. Similarly, the cowpea pod parameters measured from the two soil types used did not differ significantly. The performance of cowpea was generally better in pots that were not subjected to moisture stress with recorded highest number of pods (7.11), pod length (13.16 cm), pod weight (1.82 g), number of seeds per pod (7.91) and seed weight per pod (1.35 g).

Table 3.14: Effects of fertilizer rate, soil type and moisture regime on selected pod parameters of cowpea collected on 20 July 2018 from tunnel house trial 2

Treatment factors	No. of pods	Pod length (cm)	Pod weight (g)	No. of seeds per pod	Seed weight per pod (g)
Fertilizer rate (t ha^{-1})					
0	3.42b	9.60b	1.33a	6.52a	0.97a
10	6.75ab	13.62ab	1.70a	6.70a	1.18a
20	7.33ab	12.03ab	1.52a	6.75a	1.11a
40	8.50a	14.94a	2.03a	7.96a	1.54a
80	4.33b	11.74ab	1.53a	5.38a	1.18a
Inorganic P$^{\#!}$	5.47ab	10.24ab	1.50a	7.02a	1.17a
Soil types					
Coega	6.75a	12.59a	1.67a	5.56a	1.24a
Hutton	5.18a	11.46a	1.52a	7.89a	1.15a
Moisture regime					
No Stress	7.11a	13.16a	1.82a	7.91a	1.35a
Stress	4.82b	10.89b	1.38b	4.54b	1.03b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

3.4.5 Treatments factors and their interaction effects on selected soil chemical properties measured from the two tunnel house trials

Table 3.15 shows the ANOVA of selected chemical properties from the two tunnel house trials as influenced by different treatment factors. The results of the soil chemical properties measured under tunnel house one showed that different fertilizer rates significantly ($p \leq 0.0001$) influenced Bray-1 P and the EC of the soil. Similarly, soil types used exerted a significant ($p \leq 0.0001$) effect on the total C and the pH of the soil while moisture regime significantly ($p \leq 0.001$) influenced the soil EC. The results also revealed that the fertilizer rate and soil type interaction significantly ($p \leq 0.05$) influenced on total C and Bray-1 P content of the soil while the soil type and moisture regime interaction significantly ($p \leq 0.05$) influenced the total N and EC of the soil. However, the results of ANOVA for the measured soil chemical properties from tunnel house trial two showed that different fertilizer rates significantly ($p \leq 0.0001$) influenced all measured soil properties, with the exception of total S and soil pH. The soil types used for tunnel house two exerted a significant ($p \leq 0.05$) effect on the total S, pH, EC and Bray-1 P of the soil and also had a significant ($p \leq 0.0001$) impact on the total C and N content of the soil while moisture regime had no significant ($p \leq 0.05$) influence on all the measured soil chemical properties. The fertilizer rate and soil type interaction significantly ($p \leq 0.05$) influenced all selected soil chemical properties, with the exception of total S and pH of the soil while the soil type and moisture regime interaction significantly ($p \leq 0.05$) influenced the total N and EC of the soil. The results also showed that the fertilizer rate and moisture regime interaction did not significantly ($p \leq 0.05$) influence all the selected soil chemical properties for both tunnel house trials.

Table 3.16 shows the selected soil chemical properties measured from the two tunnel house trials. Pots fertilized with the 80 t/ha phospho-compost application rate had the soil with the highest total C (3.00 mg/g), EC (247.05 μ_s), Bray-1 P (21.67 mg/kg) under tunnel house trial one and the highest total C (3.12 mg/g), total N (0.90 g/kg) and the highest EC (2029 μ_s) under tunnel house trial two. Total S and the pH of the soil measured from the 0 t/ha rate and beyond were statistically similar under the two greenhouse trials. Similarly, the total N content of the soil measured from all the fertilizer rates under in tunnel house trial one was statistically similar. The measured total C (2.77 mg/g) and soil pH (8.06) from tunnel house trial 1 were higher in Glerosa while the highest recorded total C (3.01 mg/g), total N (0.89 mg/g), total S (0.06 mg/g) and soil pH (7.36) from the tunnel house 2 were from the Coega soil. The EC, Bray-1 P, total N and S content measured from the 2 soil types used in tunnel house trial 1 were statistically similar. The results also showed that highest soil EC (184.37 μ_s) was recorded in pots subjected to moisture stress under tunnel house trial 1 while all other soil properties measured were not statistically different from both tunnel house trials.

Table 3.15: Mean sum of squares for selected soil chemical properties measured from tunnel house trial 1 and 2

Sources of variation	**Total C (mg/g)**	**Total N (mg/g)**	**Total S (mg/g)**	**pH**	**EC (μs)**	**Bray-1 P (mg/kg)**
			Tunnel house trial 1			
Fertilizer rate	1.44*	0.12ns	2.928E-03ns	0.02495ns	25450.9***	154.99***
Soil type	6.47***	0.11ns	2.870E-04ns	3.51900***	2029.5ns	15.93ns
Moisture regime	0.07ns	0.09ns	6.301E-04ns	0.00376ns	39358.8**	1.46ns
Fertilizer rate*Soil type	0.96*	0.08ns	3.949E-04ns	0.01582ns	5759.6ns	14.88*
Soil type*Moisture regime	0.17ns	0.61*	1.449E-03ns	0.00027ns	47668.4*	3.17ns
Fertilizer rate*Moisture regime	0.50ns	0.08ns	2.154E-03ns	0.02577ns	4889.2ns	8.06ns
			Tunnel house trial 2			
Fertilizer rate	1.51***	1.56***	0.00ns	0.30818ns	3423111***	365.84***
Soil type	14.28***	3.52***	0.02*	1.23307*	1011718*	37.63*
Moisture regime	2.22E-05ns	0.01ns	0.01ns	0.06722ns	7266ns	14.12ns
Fertilizer rate*Soil type	3.04*	0.30*	0.00ns	0.01087ns	311471*	26.31*
Soil type*Moisture regime	8.89E-03ns	1.30*	0.01ns	0.02569ns	1267789*	7.03ns
Fertilizer rate*Moisture regime	2.67ns	0.10ns	0.00ns	0.04246ns	150083ns	14.22ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.16: Effects of fertilizer rate, soil type and moisture regime on Bray-1 P, total C, N, S, average pH and EC of the soil

Treatment factors	Total C (mg/g)	Total N (mg/g)	Total S (mg/g)	pH	EC (μ_s)	Bray-1 P (mg/kg)	Total C (mg/g)	Total N (mg/g)	Total S (mg/g)	pH	EC (μ_s)	Bray-1 P (mg/kg)
	Tunnel house trial 1						*Tunnel house trial 2*					
Fertilizer rate (t ha^{-1})												
0	2.14b	0.33a	0.03a	7.65a	120.43b	11.61d	2.26c	0.37b	0.06a	7.0633a	752.2b	8.76c
10	2.19b	0.39a	0.03a	7.57a	128.96b	17.25c	2.17c	0.55ab	0.03a	7.2683a	837.7b	19.67b
20	2.22b	0.36a	0.02a	7.70a	139.04b	19.00bc	2.52bc	0.57ab	0.07a	7.2667a	825.7b	20.80b
40	2.47ab	0.48a	0.03a	7.63a	162.99b	20.39ab	2.82ab	0.87a	0.04a	7.2558a	1043.6b	21.99ab
80	3.00a	0.58a	0.07a	7.63a	247.05a	21.67a	3.12a	0.90a	0.04a	7.2125a	2029.9a	22.20ab
Inorganic P[#!]	2.08b	0.36a	0.04a	7.67a	167.44b	19.86ab	2.53bc	0.70ab	0.04a	6.8700a	1691.1a	24.18a
Soil type												
Glenrosa (Coega*)	2.77a	0.50a	0.03a	8.0572a	151.32a	18.78a	3.01a	0.89a	0.06a	7.3641a	986.2b	19.28a
Hutton	1.93b	0.36a	0.04a	7.2272b	170.65a	17.81a	2.12b	0.45b	0.03b	6.9481b	1407.2a	19.92a
Moisture regime												
No stress	2.32a	0.40a	0.03a	7.6350a	137.61b	18.44a	2.57a	0.68a	0.05a	7.1256a	1186.7a	19.16a
Stress	2.38a	0.47a	0.04a	7.6494a	184.37a	18.15a	2.57a	0.66	0.04a	7.1867a	1206.8a	20.04a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control,* Implies coega used in trial 2, glenrosa used in trial 1

3.4.6 Treatment factors and their interaction effects on the total P, N and S content of cowpea plant tissues from the tunnel house trials after harvest

Table 3.17 shows the ANOVA of the chemical content of cowpea plants (total N, P and S) from the two tunnel house trials as influenced by different treatment factors. The results of plant chemical properties measured under tunnel house one showed that different fertilizer rates significantly ($p \leq 0.001$) influenced he total P and S content of cowpea plants. Soil types used exerted a significant ($p \leq 0.05$) effect on the total P content of cowpea plants in tunnel house one while moisture regime significantly ($p \leq 0.001$) influenced the total N and S content of the plants in tunnel house trial one. The results for ANOVA with regard to the chemical content of cowpea plants measured from tunnel house trial two showed that the different fertilizer rates significantly ($p \leq 0.05$) influenced the total P and N content of the plants. The fertilizer rate and soil type interaction significantly ($p \leq 0.05$) influenced on total P content of cowpea plants in both tunnel house trials while the interaction between fertilizer rate and moisture regime exerted a significant ($p \leq 0.05$) effect on the total S content of cowpea plants in tunnel house trial one. The soil type and moisture regime interaction did not have a significant ($p \leq 0.05$) influence on all selected chemical properties of cowpea plants.

Table 3.17: Mean sum of squares of total P, N and S content of cowpea plant tissues from tunnel house trials 1 and 2

Sources of variation	Trial 1			Trial 2		
	Total P	**Total N**	**Total S**	**Total P**	**Total N**	**Total S**
Fertilizer rate	0.39***	0.86ns	0.09***	0.33*	1.82*	0.02 ns
Soil type	0.09*	1.24ns	0.06ns	0.21ns	1.31ns	3.2E-03ns
Moisture regime	0.10ns	5.49**	0.07**	0.20ns	0.88ns	9.0E-05ns
Fertilizer rate*Soil type	0.08*	0.10ns	0.02ns	0.29*	0.22ns	0.02ns
Fertilizer rate*Moisture regime	0.24ns	0.36ns	0.04*	0.23ns	0.19ns	0.01ns
Soil type*Moisture regime	0.81ns	1.40ns	0.02ns	0.15ns	0.35ns	0.10ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 3.18 shows the total P, N and S of cowpea plant tissues from the two tunnel house trials. Pots fertilized with inorganic P had the highest total P (0.94 mg/kg) and S (0.54 mg/kg) in tunnel house trial one and the highest total P (0.83 mg/kg) in tunnel house trial two. The measured total N content of cowpea plant tissues from all fertilizer treatments used in both trials was statistically similar. The total S content of cowpea plant tissue from both tunnel house trials were statistically similar. Similarly, the total N, P and S content of cowpea plant tissues measured between the two soil types were statistically similar. The higher total N (1.79 mg/kg) and total S (0.44 mg/kg) were recorded in water stressed pots in tunnel house trial one while the total P, N and S contents of cowpea plant tissues were statistically similar.

Table 3.18: Effects of treatments factors on the total P, N and S content of cowpea plant tissues

Treatment factors	Total P (mg/kg)	Total N (mg/g)	Total S (mg/g)	Total P (mg/kg)	Total N (mg/g)	Total S (mg/g)
	Tunnel house trial 1			*Tunnel house trial 2*		
Fertilizer rate (t ha^{-1})						
0	0.45d	1.29a	0.29c	0.33c	1.45a	0.45a
10	0.68c	1.40a	0.41abc	0.54b	1.35a	0.43a
20	0.80bc	1.25a	0.40bc	0.65ab	1.46a	0.43a
40	0.86ab	1.46a	0.37bc	0.72ab	1.64a	0.38a
80	0.90ab	1.74a	0.47ab	0.68ab	2.16a	0.38a
Inorganic P#!	0.94a	1.93a	0.54a	0.83a	2.25a	0.48a
Soil type						
Hutton	0.81a	1.22a	0.41a	0.61a	1.58a	0.42a
Glenrosa (Coega*)	0.73a	1.80a	0.42a	0.67a	1.85a	0.43a
Moisture regime						
No stress	0.81a	1.24b	0.38b	0.59a	1.83a	0.43a
Stress	0.73a	1.79a	0.44a	0.69a	1.61a	0.42a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control * implies that Glenrosa soil used in trial 1 while Coega soil was used in trial 2

3.5 Discussion

Cowpea is an underutilised, highly valuable grain and vegetable legume crop. It is a source of food, nutritional health and income security in many African countries(Gerrano et al., 2019). In this study, the productivity of one grain cowpea variety (white flower) subjected to six fertilizer treatment rates, two soil types and two moisture regimes was assessed for agronomic parameters in a tunnel house/controlled condition while laboratory analyses were conducted upon termination of the trials. Some challenges were encountered during the running of the first tunnel house trial. The ventilation system of the tunnel house, specifically the ventilation system and the wet-wall malfunctioned while the trial was still running, thus resulting in some plants withering before they reached maturity due to heat stress largely due to high temperatures. Heat injury during late reproductive development sterilized pollen such that no fruit was set (Lucas et al., 2013), justifying why some pots did not produce any pods.

3.5.1 Mean performance of cowpea for agronomic traits, yield attributes and nutrients in tunnel house trial 1

There were significant differences in cowpea growth parameters measured between the different fertilizer rates. The significant effects of fertilizer rates on the measured cowpea growth parameters could be credited to the increase in phospho-compost application rates that ultimately enhanced crop growth, including the introduction of inorganic P fertilizer (SSP), which also had significant effects on the growth of cowpea. The 20 t/ha phospho-compost rate gave rise to the highest number of trifoliate leaves while the plant displayed the highest leaf length, leaf width and subsequently, the leaf area when fertilized with the 80t/ha phospho-compost application rate. The leaf length was the highest when 40 t/ha phospho-compost rate was used, thus contradicting Akande et al. (2005) who stated that the application of single super phosphate gave higher effects on the growth of both maize and cowpea than the use of Sokoto and Ogun rock phosphates,

Soil types used led to significant differences in cowpea growth parameters. Glenrosa soil produced a higher seed yield compared to the Hutton soil while fertilizer (compost) rate of 80t/ha) had the highest seed yield, followed by 40t/ha while treatment rate 20t/ha had the lowest seed yield. Growth parameters of cowpea were significantly higher in pots filled with Glenrosa soil, compared to the performance of cowpea in Hutton soil. The significant effect of moisture regime on the measured cowpea growth parameters is attributed to moisture stress; which is critical during plant growth despite cowpea's drought tolerance abilities. This agrees with earlier observation by Rivas et al. (2016) who stated that drought or water stress conditions reduce the potential of cowpea to produce to its maximum capability, particularly if the stress occurs before the crop starts flowering. Bastos et al. (2011) and Nascimento et al. (2011) suggested that although cowpea plants can produce more than 1,000 kg/ha, drought or water stress can reduce that potential to about 360 kg/ha, especially when the stress occurs before the crop starts flowering. Okon (2013) also reported decreased growth parameters of cowpea with an increase in water stress. Anyia and Herzog (2004) reported that water stress reduced the number of branches on average by 5–20% whereas leaf area and number of leaves were severely reduced by about 40–50%. Okon (2013) also reported that it was evident that values of all cowpea growth parameters decreased with the period of increased water stress.

There were no significant differences in the number of pods, average pod length, average pod weight, average number of seeds per pod and average seed weight per pod. The mean number of pods ranged from 5.16 to 6.17 pods between phospho-compost rates, thus contradicting the mean number of seeds per pod (13) reported by Gerrano et al. 2015) which can be attributed to differences in genotypes and trial locations. The average pod length ranged from 12.61 to 15 cm. Egbe et al. (2010) also reported pod lengths of 8.95 to 20.17 cm, while Idahosa et al. (2010) reported pod lengths of 10.57 to 18.85 cm, which are all within the range of the findings of the current study. However, there were no significant differences in the seed yield of cowpea between the fertilizer rates.

An increase in fertilizer rates resulted in an increase in available P (Bray-1 P) in the soil. The Bray-1 P content ranged from 11.61 mg/g to 21.67 mg/g with the highest P content observed in pots supplied with the 80 t/ha fertilizer. The findings are in agreement with those of Bulluck et al. (2002) who found greater enhancements in the physical, chemical, and biological characteristics of the soil in compost than synthetic fertilizers. The pH values of the soil ranged from 7.23 to 8.06 with the soil leaning towards alkalinity. Total P was significant for fertilizer rates, moisture regime resulted in significant differences in total N content while both the fertilizer rate and moisture regime caused significant differences in the total S content of cowpea plants. The total S content of cowpea plants showed an inversely proportional relationship with the fertilizer rates since total S decreased with an increase in phospho-compost application rates.

3.5.2 Mean performance of cowpea for agronomic traits, yield attributes and nutrients in tunnel house trial 2

In the second tunnel house trial, incidence of nematode infestation was observed at 9 weeks after planting in pots 6 and 16 with signs of wilting displayed by cowpea plants resulting in an ultimate death and missing data. The significant effects of fertilizer rates can be attributed to cowpea growth and development being enhanced by the increase in phospho-compost application rates and the introduction of the inorganic source of P-fertilizer (Single Superphosphate). The 80t/ha seemed to hinder the plant rather than enhance it. This was observed on the seed yield parameter whereby, the 80t/ha, despite being the highest phospho-compost rate produced the second lowest yield seed.

Moisture stress severely affected the productivity of cowpea even though cowpea can adapt to drought. The observed significant effect of moisture stress on cowpea growth parameters relates to the negative impact of moisture stress on cowpea growth. This agrees with the earlier observation made by Rivas et al. (2016) who found that drought or water stress conditions reduce the potential of cowpea to produce to its maximum capability, especially when the stress occurs during pre-flowering stages. The number of branches, leaves and the leaf area were all lower under water stress conditions. Okon (2013) also reported decreased cowpea growth parameters with an increase in water stress levels. Anyia and Herzog (2004) stated that water stress reduced the number of branches on average by 5–20% whereas, leaf area, and number of leaves were affected considerably stronger with a (40–50%) reduction. Similarly, (Okon 2013) found that it was evident for values of all cowpea growth parameters to decrease during the period of increased water stress.

Seed yields recorded in both tunnel house trials were low and this could be attributed to some cowpea plants failing to adapt to moisture deprivation. This finding agrees with (Bastos et al., 2011 and Nascimento et al., 2011) who found that cowpea plants has the potential produce more than 1000 kg/ha grain yield, but that water stress decreases that potential to approximately 360 kg/ha, which clearly shows that even though cowpea is drought-tolerant moisture is still a limiting factor. This agrees with (Saradadevi et al., 2014 and Tang et al., 2002) who found that under low moisture conditions, stomatal closure is induced by root signals, causing reductions in leaf gas exchange, which leads to loss of productivity.

The observed mean number of pods recorded per plant from the current study ranged from 3 to 9 contradicts the 10 to 31 reported by Gerrano et al. (2015) could be attributed to growth condition including moisture stress imposition that lead to flower abortion and poor pod development. The observed range of 4.54 to 7.96 for the mean number of seeds per pod in tunnel house 2 contradicts the findings of Gerrano et al. (2015) who reported mean values of 13 cowpea seeds per pod. The contradiction could be attributed to a number of factors, including varietal differences, effects of treatment effects and the growth conditions. The observed pod length ranged between 9.6 cm and 14.94 cm in the current study, this agrees with earlier ranges of 8.95 to 20.17 cm (Egbe et al., 2010) and 10.57 to 18.85 cm (Idahosa et al., 2010). The mean number of seeds per pod ranged from 4.54 to 7.96, contradicting the findings of Gerrano et al. (2015) who reported mean values of 13 cowpea seeds per pod which were obtained, this is probably because of varieties and treatments used in the two studies were different.

There were no significant differences in seed yield between crops using phospho-compost and inorganic fertilizer (single superphosphate 10.5) in the second tunnel house trial. Eghball and Power (1999) and Diez et al. (1997) also obtained no differences with regards to yields between crops grown with compost and chemical fertilizers. However, the results of the current study contradict those of Bulluck et al. (2002) who obtained improvements in crop yields from compost than inorganic fertilizer treatment. Soil filled pots supplied with the 40 t/ha phospho-compost rate flowered 48 days after planting with pod initiation at 60 days after planting; and produced the highest seed weight. This finding is in agreement with Singh et al. (2003) who found that cowpea cultivars that matured between 55 and 65 days, had good grain as well as fodder yields (this is within the range obtained in the current study). Water stressed plants flowered much earlier and formed pods faster compared to fully irrigated plants. The 40 t/ha phospho-compost application rate seemed to be ideal for growing cowpea and for most of the parameters that were measured, the crop was highly productive under phospho-compost rate. The soil types used had no significant effects on all the measured cowpea pod parameters.

Low P levels were observed in unfertilized pots in both tunnel house trials but particularly in the sandy Hutton soil. Zayed and Abdel-Motaal (2005) reported that unfertilized sandy soil did not provide cowpea plants with enough phosphorus. The total P content of cowpea plants increased with a rise in fertilizer rates with the highest total P observed in plants supplied with the 80 t/ha phospho-compost rate. Similar to tunnel house trial 1, an increase in soil amendment (fertilizer) rates resulted in increased available soil P (Bray-1 P). The observed highest Bray-1 P content of 24.18 mg/kg in inorganic P (SSP 10:5) fertilized pot as opposed to the 80 t/ha phospho-compost rate from tunnel house trial 1 is contrary to the findings of Bulluck et al. (2002).

3.6 Conclusion

The results obtained showed a variation between measured growth parameters of cowpea plants from the two tunnel house trials. In conclusion, cowpea performed better in Glenrosa and Coega soils than in Hutton soil, with generally a higher number of pods, seed yield and fodder weight. In all soil types used for both tunnel house trials, moisture stressed cowpea plants flowered earlier and formed pods quicker formation, resulted in reduced fodder weight, number of pods and ultimately lower seed yields. Although moisture stress resulted in early flowering and pod formation, the 40 t/ha phospho-compost rate seemed to be the least affected as it produced the highest (12.51 g/pot) seed yield, suggesting possible enhancement of cowpea production with phospho-compost utilization as a low-input technology practice.

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CHAPTER 4: EFFECTS OF TILLAGE AND PHOSPHO-COMPOST APPLICATION ON COWPEA PERFORMANCE GROWN UNDER RAINFED FIELD CONDITIONS

4.1 Abstract

Most agricultural soils in South Africa are nitrogen (N) and phosphorous (P) deficient, resulting in low agricultural productivity. The development of cheaper alternative (P) nutrient sources to overcome the current low soil P conditions on smallholder farmlands is critical in increasing agricultural productivity and addressing food insecurity problems in many rural poor communities where most farmers practice dryland farming. Agronomic field trial was conducted during 2017-2018-summer season to examine the impact of low-input agriculture practices on grain cowpea productivity and soil properties under rainfed conditions. Treatments consisted of two tillage practices (minimum and conventional) and six fertilizer rates of (0, 10, 20, 40 and 80 t/ha phospho-compost) with 30 kg P/ha rate inorganic fertilizer applied as a standard positive control. All treatments were replicated 3 times leading to a total of 36 plots with white seeded cowpea variety (IT00K-1217) used as a test crop. Data collected from the trial included plant height, stem diameter, number of branches, number of tri-foliate leaves, leaf length, leaf width, leaf area, number of nodules, biomass at harvest, pod parameters and seed yield at harvest. Seed germination and subsequently the emergence of plants was quicker under minimum tillage, resulting in significantly higher plant establishment and population. Tillage and the different fertilizer rates significantly influenced all the growth parameters, grain yield and yield attributes of cowpea. The 40 t/ha phospho-compost rate resulted in the highest grain yield (488.06 kg/ha) and nodule count (15.36) per plant while minimum tillage provided significantly higher grain yield (611.66 kg/ha) and nodule count (14.39) than conventional tillage. Application of phospho-compost significantly increased soil P and cowpea plant tissue P content. The heavy metal content of cowpea grains from the different fertilizer rates and tillage practices did not differ significantly ($p>0.05$) but the post-harvest soil analyses results revealed high Al and Fe concentrations with phyto-toxicity ultimately resulted in low grain yields. The implication of the high Al and Fe concentration implies that the soil pH was acidic and this affects the availability of nutrients such as Calcium, Magnesium and Phosphorous which implies that the crop will have a deficiency of these nutrients as a result.

Keywords: Dryland farming, Phospho-compost, Tillage, Cowpea production, Grain yield

4.2 Introduction

South Africa is largely a dryland and as such many farmers produce their crops under rainfed conditions. Drylands are characterised by low annual rainfall with one or two short rainy seasons. Rainfall is highly erratic with most of the rains sometimes stormy; with uneven distribution over time, leading to crop failure due to droughts whereby, soil water available for plant use is lower than the water required by the crop (Chimonyo et al., 2006). Cowpea production under dryland (rainfed) field conditions is common in South Africa, particularly among small-scale farmers. It is a highly adaptive to and able to thrive well even in less favourable conditions such as low soil fertility and erratic rainfall, which makes it an ideal crop for resource poor farmers. Aikins and Afuakwa (2010) reported that resource-poor farmers in Ghana produce cowpea under rainfed conditions, using different tillage practices. About 70% of cowpea production occurs in the drier Savannah and Sahelian zones of West and Central Africa (Hall and Patel, 1985). In these regions, cowpea is less frequently planted in monoculture or intercropped with maize (*Zea mays*), cassava (*Manihot esculenta*), or cotton (*Gossypium* sp.) (Langyintuo et al., 2003). For example, Hall and Patel (1985) reported cowpea grain yields of as much as 1000 kg ha^{-1} of dry grain in a Sahelian environment with low humidity and only 181mm of rainfall.

Most South African crop lands are characterized by nutrient deficiencies, particularly nitrogen (N) and phosphorous (P) that hamper agricultural production. However, availability of and access to inorganic fertilizers remains a problem. Many smallholder farmers in rural areas cannot readily afford commercial fertilizers. The development of cheaper alternative nutrient sources, such as compost, to improve the conditions of smallholder farmlands is critical in increasing agricultural productivity and addressing food insecurity problems in many rural poor communities. Cowpea is one of South Africa's indigenous crops mostly grown by resource-poor smallholder farmers but with relatively low productivity despite its numerous advantages. The crop is predominantly grown on dryland areas and, as such, yields are limited due to non-availability of water (Chimonyo et al., 2016). While cowpea is inherently more drought-tolerant than other crops, availability of water is still among the most significant abiotic constraints to growth and yield. Erratic rainfall at the beginning and towards the end of the rainy season adversely affects plant growth and flowering resulting in a substantial reduction in grain yield and total biomass production. In the developing world, where soil infertility is high, rainfall is limited, and most of the cowpea is grown without the use of fertilizers and plant protection measures (i.e., pesticides or herbicides). A wide variety of biotic and abiotic constraints also limit growth and severely limits yields (Singh 2005; Timko et al., 2007). At present, few other legume crops are capable of producing significant quantities of grains under these conditions.

Cowpea is a valuable component of farming systems in areas where soil fertility is a limiting factor because of its ability to fix high rates of nitrogen. It also has the ability to tolerate a wide range of soil pH compared to other grains. Cowpea is also well-recognized as a key component in crop rotation schemes because of its ability to help restore soil fertility for succeeding cereal crops (Tarawali et al., 2002; Sanginga et al., 2003). The introduction of low-input agriculture practices could also prove very useful for farmers concerned about high input costs. The use of conservation tillage such as minimum or zero tillage could provide an alternative that is cheaper than the currently used conventional tillage systems. Tillage is a very important activity in crop production and it can affect the performance of the crop differently as inappropriate tillage practices can hinder crop growth and ultimately yields (Aikins and Afuakwa, 2010). However, because of its highly adaptive nature, cowpea can be grown successfully even when minimum tillage is practised.

The adoption of cowpea, despite its numerous advantages, remains low, particularly among commercial farmers. This has resulted in the crop being marginalized compared to cereal crops such as maize and wheat. Cowpea is a grain legume with a lot of merits. It has high vegetative growth and covers the ground so well that it checks soil erosion (Singhal et al., 2015). Due to its ability to fix nitrogen in the soil, cowpea meets its own requirements and leaves a fixed nitrogen deposit in the soil up to 60-70 kg/ha for the succeeding crop (Tilak and Singh, 1996). One of the important constraints that limits the production of grain legumes is inadequate supply of phosphorus. The adequate supply of phosphorus to legume is more important than that of nitrogen because of its beneficial effect on nodulation, growth and yield. The study sought to evaluate the performance of cowpea and soil chemical properties under dryland conditions following phospho-and imposition on two distinct tillage systems.

4.3 Materials and methods

4.3.1 Description of the study area

The field trial and the subsequent residual field trial were conducted at the North-West University experimental farm, commonly referred to as Molelwane, found in North West Province. The trial site was located at 25° 47" 376'S, 025° 37" 164E, 1290.76 metres above sea level.

4.3.2 Land preparation and pre-planting, soil sampling and analyses

Preparation of the land involved both conventional and minimum (or reduced) tillage systems. Minimum tillage has many benefits far and above conventional tillage yet, the latter is still widely practiced. Minimum tillage minimized soil disturbances and allows crop residues to be retained on the ground, thus preventing soil erosion (Boucher 2008), while conventional tillage produces a fine clean seedbed with breakdown in soil structure, leaving the soil with very little or no cover by removing plant residues from the previous crop (Environmental Indicators for Agriculture 2001). Minimum tillage involved chisel plough of the field to provide minimal soil disturbance while conventional tillage involved the use of chisel plough followed by a disc plough and a harrow in order to obtain a fine, clean, level and well-pulverised soil (Kutu 2012). Minimum tillage entailed the running of single tractor chisel plough of the field followed by planting while conventional tillage involved ploughing the field twice with implements such as a disc plough and a harrow. Pre-planting soil samples randomly were collected at surface (0-15 cm) and sub-surface (15-30 cm) depths on the field and then mixed according to the depth of collection to obtain a representative sample. Collected soil samples were analysed at the NWU Crop Science laboratory.

4.3.3 Description of experiment, treatments, design and field layout

The experimental design was a split plot arrangement fitted into a randomized complete block design. The trial consisted of two factors namely; tillage and fertilizer application rates. Tillage treatment constituted the main plot while fertilizer rates made up the sub-plot. Sole grain cowpea variety (white seeded cowpea) was planted while low-input fertilizer rates applied comprised (0, 10, 20, 40, 80) t/ha. Inorganic P fertilizer rate of 30 kg/ha was included to serve as a standard positive control. Treatments in the trial were replicated 3 times, leading to a total of 36 experimental treatment units (subplots). The size of each subplot was 4.5 m in x 3.6 m, consisting of 5 cowpea rows with intra-row spacing of 20 cm and an inter-row spacing of 90 cm. The total land area used in this study at each site was 1105.64 m^2. Planting of trial was under rainfed condition with supplementary irrigation only provided during the early stage to promote good crop establishment. Trial planting was during the summer season of 2017/2018. residual effect of treatments was assessed after the trials were terminated. Pre-emergence herbicides consisting of a mixture of dual gold (200 ml) and paraquat (200 ml) in a 15 L Knapsack sprayer was applied immediately after seed sowing. Regular spraying of karate was done to control insect pests, particularly aphids infestation at flowering and beyond.

4.3.4 Data collection from the field study

Data collection from the field trial was done at vegetative, flowering and physiological maturity stages. Measured cowpea growth parameters were at 5, 7, 9 and 11 weeks after planting (WAP). These included plant height determined using a metre rule and stem diameter determined using a vernier caliper. Others included: number of branches and number of tri-foliate leaves per plant determined by count; leaf length measured from the petiole to the tip of the trifoliate leaf and leaf width measured from the two points where the leaf was the broadest using a steel metre tape. The healthiest trifoliate leaf possible was chosen for the measurement of leaf length and width and expressed in centimetres while leaf area was estimated using the equation (L* W*2.325), according to Osei-Yeboah et al. (1983) with L representing the length of the selected leaf and W being the width of the leaf. Phenological parameters included the number of days to 50 and 100% flowering, number of days to 100% pod formation, number of nodules and nodule weight determined at 100% flowering. Plant biomass, pod characteristics (e.g. number of pods per plant, pod length, pod weight, number of seeds per pod) and average seed weight per pot (i.e. grain yield) were recorded at harvest. Postharvest soil and plant analyses were done after the termination of the trial.

4.3.5 Description of laboratory analyses of soil and plant tissue samples

Laboratory analyses of the field trial were done at nodulation and postharvest stages. Soil samples taken from the trials were air dried and then passed through a 4mm sieve while plant samples were oven dried and then milled, thereafter, both the soil and plant samples were subjected to detailed chemical analysis. Measurement of pH and electrical conductivity in soil/water suspension (1:2.5) using PHS-3BW pH metre and DDS-11AW Benchtop conductivity meter, respectively. Soil available P measurement following Bray-1 extraction procedure was on a SP-UV 300SRB Spectrophotometer. The determination of total Carbon, Nitrogen and Sulphur was done using the LECO Trumac CNS analyser. The heavy metal content of cowpea grains and soil samples was done using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) iCAP RQ ICP-MS instrument.

4.3.6 Statistical analyses

Growth and yield data generated from the trial was subjected to statistical analysis, performed using Analysis of Variance (ANOVA) Statistix 10.0 version. The Least Significant Difference (LSD) test was then performed at $p \leq 0.05$ to establish significant difference between treatment means. Linear correlation analysis was run between selected growth and yield attributes.

4.4 Results

4.4.1 Treatment factors and their interaction effects on selected cowpea growth parameters evaluated under dryland conditions

Table 4.1 shows the ANOVA of cowpea growth parameters as influenced by different treatment factors. The results for measured growth parameters showed that the sampling date exerted a significant ($p \leq 0.0001$) effect on plant height, stem diameter, number of branches, number of leaves, leaf length, leaf width and leaf length. On the other hand, the different fertilizer rates similarly exerted significant ($p \leq 0.0001$) influence on the stem diameter, number of branches, number of leaves, leaf length, leaf width and leaf area. The sampling date was also the only treatment factor that significantly ($p \leq 0.0001$) influenced the chlorophyll content of cowpea plants.

Tillage systems used significantly ($p \leq 0.0001$) influenced plant height, stem diameter, number of branches, number of leaves, leaf length, leaf width and leaf area. The interaction between sampling date and fertilizer rate significantly ($p \leq 0.05$) influenced stem diameter, while the other growth parameters were not. Results also showed that the interaction between sampling date and tillage significantly ($p \leq 0.05$) influenced the stem diameter, number of branches and leaf length but exerted no significant ($p \leq 0.05$) effect on the leaf length and the leaf area.

The fertilizer rate and tillage interaction significantly ($p \leq 0.0001$) influenced the plant height, leaf length, leaf width and leaf area. The interaction also had a significant ($p \leq 0.05$) effect on the stem diameter and number of branches of cowpea plants, while the three-way interaction between sampling date, fertilizer rate and tillage did not significantly ($p \leq 0.05$) influence any of the measured cowpea growth parameters.

Table 4.1: ANOVA table of the measured cowpea growth parameters as affected by treatment factors and their interactions

Sources of variation	**Plant height (cm)**	**Stem diameter (cm)**	**No. of Branches**	**No. of leaves**	**Chlorophyll (CCI)**	**Leaf length (cm)**	**Leaf width (cm)**	**Leaf area (cm^2)**
Sampling date (SD)	11064.8***	14.39***	728.18***	13426.3***	59593.9***	66.18***	48.49***	71117.8***
Fertilizer rate (FR)	109.8*	0.116***	17.50***	346.4***	519. ns	7.25***	4.65***	7510.7***
Tillage (T)	9260.1***	2.09***	418.61***	9849.4***	2819.0ns	66.01***	36.63***	61990.2***
SD*FR interaction	18.5ns	0.03*	2.65ns	59.1ns	646.0ns	1.20ns	0.41ns	730.1ns
SD*T interaction	191.6**	0.06*	5.75*	57.9ns	1965.3ns	1.83ns	1.61*	1320.1
FR*T interaction	225.5***	0.06*	6.04*	175.4**	654.2ns	5.57***	2.0***	3908.8***
SD*FR*T interaction	48.9ns	0.01ns	2.377ns	23.8ns	921.1ns	0.3087ns	0.19ns	165.4ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 4.2 shows that different fertilizer rates had significant effects on cowpea growth. The recorded highest chlorophyll content (94.13 CCI) was at 9 weeks after planting (WAP) while all other growth parameters were higher 11 WAP. The performance of cowpea was poor at the 5 WAP growth stage on these growth parameters, which can be credited to the plants being in the early parts of their establishment. The tallest plants (43.39cm), widest stems (0.84 cm), highest number of branches (5.68), highest number of trifoliate leaves (24.56), longest leaves (10.39 cm), and widest leaves (6.18 cm) and the highest leaf area (151.15 cm^2) were all from plots fertilized with the 80 t/ha phosphor-compost application rate. Only the chlorophyll content was higher (85.09 CCI) in plots fertilized using inorganic P. The shortest plants (40.62 cm), smallest stem diameter (0.76 cm), least number of branches (4.58), least number of trifoliate leaves (20.09), least leaf width (5.65 cm) and the least leaf area (130.56 cm^2) were all obtained from the plot fertilized with 10 t/ha phospho-compost application rate. The least chlorophyll content (79.02 CCI) and the shortest leaves (9.73 cm) were obtained from plots amended with 20 t/ha phospho-compost rate.

The performance of cowpea was generally better in plots prepared using minimum tillage with recorded tallest plants (45.31 cm), widest stems (0.85 cm), highest number of branches (5.75), leaves 25.75), longest leaves (10.26 cm), widest leaves (6.05 cm) and the highest leaf area (145.93 cm^2) while plots prepared using conventional tillage performed poorly on all cowpea growth parameters measured comparatively.

Table 4.2: Effects of sampling date, fertilizer rate and tillage on selected growth parameters collected 5, 7, 9 and 11 weeks after planting

Treatment factors	Plant height (cm)	Stem diameter (cm)	No. of branches	No. of trifoliate leaves	Chlorophyll (CCI)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
Sampling date (Weeks after planting) WAP								
5	31.96d	0.40d	2.74d	12.0d	55.10c	9.23c	5.15c	112.09c
7	39.20c	0.82c	4.07c	18.12c	93.0a	9.68b	5.69b	129.17b
9	45.95b	0.90b	5.78b	27.24b	94.13a	10.36a	6.19a	150.15a
11	49.78a	1.06a	7.36a	30.96a	83.63b	10.54a	6.28a	155.20a
Fertilizer rate, FR (t ha^{-1})								
0	41.86ab	0.76b	4.81bc	20.93c	80.35a	9.76b	5.69bc	130.84c
10	40.62b	0.76b	4.58c	20.09c	80.54a	9.82b	5.65c	130.56c
20	41.66ab	0.82a	5.13b	23.63ab	79.02a	9.73b	5.84bc	134.05bc
40	40.98b	0.82a	4.95bc	21.77bc	81.67a	10.04b	5.90b	140.21b
80	43.39a	0.84a	5.68a	24.56a	82.11a	10.39a	6.18a	151.15a
Inorganic P[#!]	41.81ab	0.77b	4.79bc	21.36c	85.09a	9.96b	5.71bc	133.11bc
Tillage								
Minimum	45.31a	0.85a	5.75a	25.75a	83.44a	10.26a	6.05a	145.93a
Conventional	38.13b	0.74b	4.23b	18.36b	79.49a	9.65b	5.6b	127.37b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

4.4.2 Treatment factors and their interaction effects on selected cowpea yield and yield attributes evaluated under dryland conditions

Table 4.3 shows the ANOVA for nodule count, yield and yield attributes of cowpea as influenced by different treatment factors. The results show that different fertilizer rates and the interaction between fertilizer rates and tillage had no significant ($p \leq 0.05$) influence on the nodule count, biomass at nodulation, plant population at harvest, grain yield, 100 seed weight and all cowpea pod parameters measured. Tillage, however, had a significant ($p \leq 0.05$) influence on biomass at nodulation, plant population at harvest, pod weight, number of seeds per pod and seed weight per pod. Additionally, tillage systems significantly ($p \leq 0.0001$) influenced 100 seed weight and pod length of cowpea. All treatment factors did not significantly ($p \leq 0.05$) influence the measured parameters such as nodule count, fresh and dry weight of 20 green pods of cowpea.

Table 4.4 shows that yield and yield attributes of cowpea such as nodule count, biomass at nodulation, plant population at harvest, grain yield and 100 seed weight measured from all the phospho-compost application rates were statistically similar. The performance of cowpea was generally better in plots prepared using minimum tillage with recorded highest plant biomass at nodulation (42.59g), plant population harvested (59499), highest grain yield (611.66 kg/ha) and highest 100 seed weight (18.44g) while nodule count measured from the two tillage systems were statistically similar.

Table 4.3: ANOVA of measured cowpea growth parameters, yield and yield attributes as affected by treatment factors and their interactions

Sources of variation	**Nodule count**	**Biomass at nodulation (g)**	**Plant population at harvest**	**Grain yield (kg/ha)**	**100 seed weight (g)**	**Pod length (cm)**	**Pod weight (g)**	**No. of seed pod^{-1} (g)**	**Seed weight pod^{-1} (g)**	**Fresh weight of 20 green pods (g)**	**Dry weight of 20 green pods (g)**
Fertilizer rate (FR)	57.29ns	59.56 ns	1.139E+08ns	63049ns	0.38ns	0.31ns	0.08ns	1.27ns	0.07ns	341.46ns	8.63ns
Tillage (T)	80.22ns	3116.29*	4.150E+08*	571801**	14.25***	4.74***	0.40*	7.34*	0.35*	785.59ns	0.96ns
FR*T interaction	87.42ns	105.14 ns	5.081E+07ns	70496ns	0.43ns	0.07ns	0.02ns	1.59ns	0.01ns	177.92ns	8.05ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 4.4: Effects of fertilizer rate and tillage on nodule count, plant biomass at nodulation and selected yield parameters

Treatments	Nodule count	Biomass at nodulation (g)	Plant population harvested	Grain yield (kg/ha)	100-seed weight (g)
Fertilizer rate, FR (t ha^{-1})					
0	14.20a	35.76a	61523a	471.81a	17.56a
10	15.29a	39.20a	59671a	484.36a	18.05a
20	9.62a	38.15a	51029a	380.86a	17.48a
40	15.36a	33.54a	54321a	488.06a	18.07a
80	12.04a	34.20a	51749a	450.21a	17.77a
Inorganic $P^{\#!}$	13.45a	35.21a	58334a	638.48a	17.94a
Tillage					
Minimum	14.39a	42.59a	59499a	611.66a	18.44a
Conventional	12.26a	29.43b	52709b	359.60b	17.18b

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 4.5 shows that pod characteristics of cowpea measured from all the phospho-compost rates used were statistically similar. There were significant differences in pod characteristics of cowpea between the two tillage practices. The performance of cowpea was generally better in plots prepared using minimum tillage with recorded longest pods (16.31 cm), highest pod weights (2.90g), highest number of seeds per pod (11.89) and highest seed weights per pod (2.21g). However, significant differences in fresh and dry weight of the collected 20 green pods were observed between the two tillage practices.

4.4.3 Treatment factors and their interaction effects on measured soil chemical properties and cowpea plants from the field trial

Table 4.6 shows the ANOVA for Bray-1 P content of the soil and the total P content of cowpea plants as influenced by different treatment factors. The results show that different fertilizer rates significant ($p \leq 0.05$) influenced the Bray-1 P of the soil and the total P content of cowpea plants at nodulation. Different fertilizer rates also had a significant ($p \leq 0.0001$) effect on the P content of the soil at postharvest. Tillage systems used and the interaction between fertilizer rates and tillage did not significantly ($p \leq 0.05$) influence the Bray-1 P of the soil and the total P content of cowpea plants at both nodulation and postharvest stages.

Table 4.7 shows that at nodulation plots fertilized with the 40 t/ha phospho-compost rate had the highest Bray-1 P (18.90 mg/kg) and at postharvest plots fertilized with the 80 t/ha phospho-compost rate had the highest Bray-1 P (12.58 mg/kg) content in the soil. Plots fertilized with inorganic P had the highest total P content in cowpea plants (0.65 mg/kg) at nodulation and (0.88 mg/kg) at postharvest. Significant differences were observed in the Bray-1 P content of the soil and the total P content of cowpea plants at both the nodulation and postharvest stages.

Table 4.5: Effects of fertilizer rate and tillage on various pod parameters measured 11 May 2018 and 20 green pods measured 24 April 2018

Treatments	Pod length (cm)	Pod weight (g)	No. of seeds pod^{-1}	Seed weight pod^{-1} (g)	Fresh weight of 20 green pods (g)	Dry weight of 20 green pods (g)
Fertilizer rate, FR (t ha^{-1})						
0	15.72a	2.66a	11.46a	1.97a	121.78a	18.37a
10	15.91a	2.73a	10.79a	2.05a	140.45a	19.12a
20	16.33a	2.96a	11.88a	2.28a	126.14a	17.25a
40	16.07a	2.89a	11.75a	2.18a	132.93a	19.02a
80	15.92a	2.82a	11.79a	2.13a	120.32a	16.19a
Inorganic P[#!]	15.76a	2.72a	10.96a	2.03a	125.98a	16.94a
Tillage						
Minimum	16.31a	2.90a	11.89a	2.21a	132.61a	17.98a
Conventional	15.59b	2.69b	10.97b	2.01b	123.26a	17.65a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 4.6: ANOVA of the analysed P content in the soil and cowpea plant tissues as affected by treatment factors and their interactions

Sources of variation	Bray1 P (soil) nodulation (mg/kg)	Bray1 P (soil) postharvest (mg/kg)	Total P (plants) nodulation (mg/kg)	Total P (plants) postharvest (mg/kg)
Fertilizer rate	57.63*	55.52***	0.10*	0.24**
Tillage	3.04 ns	2.57 ns	0.01 ns	1.40E-03
Fertilizer rate*Tillage	3.74 ns	3.01 ns	0.28 ns	1.24E-02

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 4.7: Effects of fertilizer rate and tillage on the P content of the soil and cowpea plant tissue at nodulation and postharvest stages

Treatments	Bray-1 P at nodulation (mg/kg)	Bray-1 at postharvest (mg/kg)	Total P (plants) Nodulation (mg/kg)	Total P (plants) Postharvest (mg/kg)
Fertilizer rate				
0 t/ha	13.62ab	4.95d	0.33c	0.35c
10 t/ha	12.18ab	8.13bcd	0.46bc	0.48bc
20 t/ha	16.76ab	9.83abc	0.50ab	0.65ab
40 t/ha	18.90a	11.69ab	0.53ab	0.74a
80 t/ha	14.74ab	12.58a	0.63ab	0.80a
Inorganic P[#!]	10.325b	6.08cd	0.65a	0.88a
Tillage				
Minimum	14.71a	8.61a	0.53a	0.64a
Conventional	14.13a	9.14a	0.50a	0.66a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

Table 4.8 shows the ANOVA Total C, N, S, soil pH and electrical conductivity as influenced by different treatment factors. The results showed that different fertilizer rates significantly ($p \leq 0.0001$) influenced the total C content. Similarly, the average EC of the soil was significantly ($p \leq 0.0001$) influenced by different fertilizer rates and the sampling stages. Total N and average pH were also significantly ($p \leq 0.05$) influenced by different fertilizer rates. Tillage systems used significantly ($p \leq 0.05$) influenced the total C of the soil while the fertilizer rate and tillage interaction significantly ($p \leq 0.05$) influenced the total C content and average EC of the soil. The tillage and sample stages interaction as well as the interaction between fertilizer rates and sample stages did not significantly ($p \leq 0.05$) influence the total C, N, S, average pH and EC of the soil.

Table 4.8 also show that plots fertilized with 80 t/ha phospho-compost rate had the highest total C (3.43 mg/g) and the highest EC (131.57μ_s) in the soil while plots fertilized with the 40 t/ha phospho-compost application rate had the highest total N (0.90 mg/g) content in the soil. Total S and soil pH were statistically similar for all the applied phospho-compost rates. The plots prepared using minimum tillage had a significantly higher total C content (2.52 mg/kg) while soil pH (7.79) and average EC of the soil (105.76 μ_s) were all higher at postharvest. The total N, S content, soil pH and average EC between the two tillage systems was statistically similar. The results also showed no significant differences in the total C, N and S content of the soil nodulation and postharvest.

Table 4.9 shows the ANOVA of total N and S in cowpea fodder at nodulation and postharvest. The results showed that fertilizer rate significantly ($p \leq 0.05$) influenced the total S content at postharvest. The results also showed that tillage systems had no significant ($p \leq 0.05$) influence on the total N and S content of cowpea plants at both sampling stages. The highest total S content (0.03 mg/kg) of plant tissue recorded at postharvest was in plots supplied with 10 and 40 t/ha phospho-compost rates while the total N and S measured from all the phospho-compost application rates was statistically the same.

Table 4.8: Total soil C, N, S pH and Electrical conductivity (EC) as affected by treatment factors and their interactions

Treatments	Total C (mg/g)	Total N (mg/g)	Total S (mg/g)	pH	EC (μ_s)
Fertilizer rates, FR (t ha^{-1})					
0	2.08c	0.43b	0.09a	7.82a	70.87b
10	2.16c	0.56ab	0.32a	7.70a	77.35b
20	2.18c	0.48b	0.05a	7.68a	89.73b
40	2.69b	0.90a	0.07a	7.65a	101.54ab
80	3.43a	0.76ab	0.08a	7.64a	131.57a
Inorganic P[#!]	1.96c	0.51b	0.04a	7.81a	75.28b
p-value	***	*	ns	ns	***
Tillage (T)					
Minimum	2.52a	0.54a	0.08a	7.70a	91.73a
Conventional	2.28b	0.67a	0.04a	7.73a	90.39a
p-value at 5%	*	ns	ns	ns	ns
Sampling stages (Ss)					
Nodulation	2.40a	0.65a	0.08a	7.64b	76.36b
Postharvest	2.40a	0.56a	0.04a	7.79a	105.76a
p-value at 5%	ns	ns	ns	*	***
Interaction					
FR*T	*	ns	ns	ns	*
FR*Ss	ns	ns	ns	ns	ns
T*Ss	ns	ns	ns	ns	ns

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control, * & *** implies significant at 5% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 4.9: Effects of fertilizer rate and tillage on the total N and S content of cowpea plant tissues at nodulation and postharvest stages

Treatments	Nodulation		Postharvest	
	Total N	Total S	Total N	Total S
Fertilizer rate, FR (t ha^{-1})				
0	1.51a	0.20a	2.11a	0.01b
10	1.80a	1.18a	1.66a	0.03a
20	1.59a	0.22a	1.81a	0.02ab
40	1.86a	0.22a	2.03a	0.03a
80	2.47a	0.19a	2.27a	0.02ab
Inorganic P[#!]	1.71a	0.19a	1.81a	0.02ab
p-value at 5%	ns	ns	ns	*
Tillage practices				
Minimum	2.00a	0.52a	2.01a	0.02a
Conventional	1.78a	0.21a	1.89a	0.02a
p-value at 5%	ns	ns	ns	ns
FR*T interaction	ns	ns	ns	ns

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control while * and ns implies significant and not significant, respectively at 5% probability level

4.4.4 Cowpea grains N, P, K, S and metal content as affected by different treatment factors and their interaction

Table 4.10 shows the ANOVA of total N, P, K and S content found in cowpea grains. The results show that different fertilizer rates and the interaction between fertilizer rate and tillage had no significant ($p \leq 0.05$) influence on the total N, P, K and S content of cowpea grains. Tillage systems used significantly ($p \leq 0.05$) influenced the total S content of cowpea grains. However, the results of the ANOVA for the nutrient content of cowpea grains showed that tillage systems used did not have a significant ($p \leq 0.05$) influence on the total N, P and K content of cowpea grains.

No significant differences were observed in the total N, P, K, and S content of cowpea grains between the different fertilizer rates. Tillage systems used exerted no significant effect on the total C, N, P and K content of the grains. However, there were significant differences in the total S content of cowpea grains between the two tillage systems used with plots prepared using conventional tillage, having a higher total C content (0.04 mg/g) compared to plots prepared using minimum tillage. Plots prepared using conventional tillage had a higher total S content (0.04 mg/g) while the measured total N, P, K and S content of cowpea grains for all the phospho-compost application rates were statistically similar.

Table 4.10: Effects of treatment factors and their interactions on the total N, P, K, S content of cowpea grains

Treatments	Nitrogen (N) (mg/g)	Phosphorus (P) (mg/kg)	Potassium (K) (mg/kg)	Sulphur (S) (mg/g)
Fertilizer rate, FR (t ha^{-1})				
0	7.05a	3502.3a	12181a	0.040a
10	6.83a	3880.9a	13320a	0.042a
20	7.06a	3705.3a	12155a	0.020a
40	7.09a	3731.0a	12575a	0.035a
80	7.00a	3654.3a	12242a	0.023a
Inorganic P$^{\#!}$	6.78a	3683.7a	12575a	0.023a
p-value at 5%	ns	ns	ns	ns
Tillage practices (T)				
Minimum	6.96a	3627.7a	12018a	0.02a
Conventional	6.97a	3760.9a	12973a	0.04b
p-value at 5%	ns	ns	ns	*
FR*T interaction	ns	ns	ns	ns

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control while * and ns implies significant and not significant, respectively at 5% probability level

Table 4.11 shows the ANOVA of the heavy metal content found in cowpea grains. The results showed that the heavy metals found in cowpea grains were not significantly ($p \leq 0.05$) influenced by the different fertilizer rates. The tillage system used and the interaction between fertilizer rates and tillage did not significantly ($p \leq 0.05$) influence the heavy metal content of cowpea grains. Table 4.12 shows that the heavy metal (total Ca, Mg, Na, Mn, Fe, Cu, Zn, As, Cd, Pb, Ni and Al) content measured from all the phospho-compost were statistically the same.

Table 4.11: Mean sum of squares of the analysed metal content of cowpea grains as affected by different treatment factors

Nutrients	Fertilizer rates (FR)	Tillage (T)	FR*T interaction
Ca	1418296ns	805716ns	1410640ns
Mg	55993ns	2070ns	77787ns
Na	399.83ns	36.20ns	160.18ns
Mn	14.15ns	2.10ns	13.19ns
Fe	2247.49ns	724.15ns	2664.95ns
Cu	0.16ns	0.17ns	0.36ns
Zn	8.98ns	3.87ns	17.88ns
As	$2.52E^{-03}$ns	$1.78E\text{-}^{04}$ns	1.87E-03
Cd	$1.17E^{-05}$ns	0.00ns	$7.33E^{-05}$ns
Pb	$3.14E^{-03}$ns	$1.34E^{-03}$ns	$1.98E^{-03}$ns
Ni	1.80ns	$4.70E^{-03}$ns	1.02ns
Al	517.28ns	146.09ns	562.54ns

*, ** & *** Implies significant at 5%, 1% & 0.1%, respectively while ns implies not significant at 5% probability level

Table 4.12: Metal content of cowpea grains (mg/kg) as influenced by different fertilizer rates and tillage practices

Treatments	Ca	Mg	Na	Mn	Fe	Cu	Zn	As	Cd	Pb	Ni	Al
Fertilizer rate (t ha^{-1})												
0	1128.3a	1854.2a	81.10a	13.78a	112.38a	6.83a	32.18a	0.15a	0.06a	0.19a	14.72a	33.26a
10	1178.9a	2019.0a	91.98a	14.32a	116.73a	6.91a	33.12a	0.14a	0.05a	0.22a	16.05a	34.98a
20	2368.5a	2129.0a	105.25a	17.58a	160.23a	6.62a	32.79a	0.18a	0.05a	0.23a	15.26a	56.51a
40	1206.3a	1921.5a	91.59a	13.54a	108.99a	6.51a	30.54a	0.14a	0.06a	0.16a	15.40a	32.42a
80	1133.3a	1948.0a	88.18a	13.47a	112.53a	6.55a	30.32a	0.15a	0.06a	0.20a	15.48a	33.55a
Inorganic P[#!]	1280.3a	1916.2a	86.17a	14.31a	115.95a	6.78a	30.79a	0.12a	0.06a	0.19a	16.22a	35.47a
Tillage practices												
Minimum	1532.2a	1957.1a	89.71a	14.74a	125.62a	6.63a	31.29a	0.15a	0.05a	0.19a	15.53a	39.71a
Conventional	1233.0a	1972.2a	91.72a	14.26a	116.65a	6.77a	31.95a	0.14a	0.05a	0.20a	15.51a	35.68a

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control

4.4.5 Treatment factors and their interaction effects on the total N and S content of cowpea green pods

Table 4.13 shows the ANOVA of the total N and S content of cowpea green pods as influenced by different treatment factors. The results showed that different fertilizer rates, tillage as well as the interaction between the fertilizer rates and tillage had no significant ($p \leq 0.05$) influence on the total N and S content of cowpea green pods. Nevertheless, the contents of total N (7.08 mg/g) and S (0.31 mg/g) were highest in green pods in plots supplied with the 20 t/ha phospho-compost rate. The total N and S of cowpea green pods measured from the two tillage systems was statistically similar.

Table 4.13: Effects of fertilizer rate and tillage on total N and S content of cowpea green pods

Treatments	Total N (mg/g)	Total S (mg/g)
Fertilizer rate (t ha^{-1})		
0	6.94a	0.20a
10	7.10a	0.19a
20	7.34a	0.31a
40	7.01a	0.21a
80	7.08a	0.20a
Inorganic $P^{\#!}$	6.46a	0.19a
p-value at 5%	0.13ns	1.23ns
Tillage practices		
Minimum	7.12a	0.57a
Conventional	6.90a	0.20a
p-value at 5%	0.08 ns	1.19ns
Fertilizer rate*Tillage	0.07ns	1.21ns

#! Implies inorganic P fertilizer (SSP) rate of 30 kg/ha applied as standard positive control while ns implies not significant at 5% probability level

4.5 Discussion

Cowpea is a crop that has the potential to solve food insecurity challenges that are prevalent in many developing countries in sub-Saharan Africa. Singh and Reddy (2011) stated that among all legumes, cowpea has the maximum diversity for plant type, growth habit, maturity, seed type and adapt well to a wide range of environments hence, serves as a model legume crop. Production of cowpea under dryland conditions is a common practice among smallholder farmers. It is a resilient crop that thrives even under the least favourable conditions, which makes it an ideal crop for even the most resource-poor farmers (Mupangwaa et al., 2012). It is a highly suitable crop and has ability to thrive under minimum tillage, where there is minimal soil disturbance, which on the part of resource-poor smallholder farmers, could result in reduced costs and soil conservation. This supports the assertion by Mupangwaa et al. (2012) that smallholder farmers, using reduced tillage systems, stand a better chance of timely planting and getting higher crop yields compared to those using the traditional conventional system. Reduced tillage offers a viable opportunity to increase crop productivity in the long-term and in a sustainable manner (Hobbs 2007; Govaerts et al., 2009; Kassam et al., 2009; Wall 2009; Thierfelder and Wall 2010).

The significant influence of the date of sampling with on all cowpea growth parameters measured, with the exception of chlorophyll content at 10 WAP, is an indication that cowpea growth was impacted upon after the imposition of moisture stress. Plants grown in plots prepared using reduced tillage, emerged and established faster than those prepared under conventional tillage. This is in agreement with the findings of Mupangwaa et al. (2012) who found that although tillage may not significantly influence grain yield, it significantly affected the establishment of crops. Cowpea plants grown under dryland conditions and reduced tillage attained flowering stage earlier and produced pods quicker, resulting in higher grain yield than under conventional tillage. This is agreement with the findings of Moroke et al. (2011) who found that drought-adapted, early maturing crops combined with reduced tillage systems, have the potential to stabilize and increase dryland crop yields in the drier regions of the world.

Application of phospho-compost exerted better influence on growth parameters of cowpea than inorganic P fertilizer (Single Superphosphate). This could be attributed to phospho-compost being a much better fertilizer source than inorganic fertilizers primarily because of the many benefits associated with using compost. The growth parameters were all significantly higher under the reduced tillage system compared to the conventional tillage system. The grain yield from many of the plots was generally very low due to poor plant establishment observed, resulting from attacks by rodents and pests, attack with sown seeds often removed despite several attempts to gap fill. Other contributory factors to the observed low cowpea grain yields included guinea fouls attacks on the green and dried pods. The observed range of hundred seed weight (17.18 to 18.44g) reported in the current study agrees with the findings of Gerrano et al. (2015) who obtained a range of 7.79 to 18.67g for hundred seed weight. However, the results are much higher than the range of 8.97 to 13.40 g reported by Idahosa et al. (2010) from Nigeria for eight cowpea lines.

The results obtained in this study clearly showed variable responses of the performance of cowpea to various fertilizer (phospho-compost) treatments under two tillage practices. The reported leaf area of cowpea plants observed in the current study contradicts the findings of Ahamefule and Peter (2014) who found that highly tilled plots produced significantly larger leaf area indices while the larger leaf area in the current study was observed in plots prepared using minimum tillage. Generally, all cowpea growth parameters were higher under reduced tillage, which agrees with earlier findings of (Hobbs, 2007; Govaerts et al., 2009; Kassam et al., 2009; Wall, 2009; Thierfelder and Wall, 2010). Various researchers reported that reduced tillage offers a viable opportunity to increase productivity for crops such as cowpea in a sustainable manner, *thus explaining* why the performance of cowpea was generally better in plots prepared using minimum tillage

There was a challenge of poor plant stands in some of the plots, resulting in the productivity of the crop being affected and reducing the yield of the crop dramatically. Poor cowpea plant stands could be attributed to seed predation by squirrels, which is similar to the remarks made by Mupangwaa et al. (2012) who stated that there were poor plant stands at Matopos experimental fields (due to seed predation by rodents) which negatively impacted the growth and establishment of cowpea. Yield was also significantly affected by the chemical toxicity that resulted from the spraying of pre-plant herbicides and pesticides, which stunted the growth of cowpea at emergence.

The reported range of 59.8 to 68.0 days to attainment of 50% flowering from the current study contradicts earlier findings by Nagalakshmi et al. (2010) who reported that cowpea attained 50% flowering 27.50 days after planting could be attributed to varietal differences. Ige et al. (2011) reported 39 days to 50% in Nigeria while Cobbinah et al. (2011) reported 31–38 days in Ghana for different cowpea genotypes used in their studies. The reported pod length ranges of 15.72 cm to 16.33 cm which is comparable to the results obtained by Gerrano et al. (2015) who obtained cowpea pod lengths range of 10.88 to 18.90 cm. The reported cowpea pod length of 8.95 to 20.17 cm (Egbe et al., 2010) and 10.57 to 18.85 cm (Idahosa et al., 2010) all fall within the current findings. The observed highest cowpea grain yield in inorganic P fertilized plot agrees with the work of Akande et al. (2015) who reported the superiority of single super phosphate over rock phosphates or its combination with poultry manure.

Unexpectedly, the grain yield obtained from unfertilized plots was higher than that obtained from all the phospho-compost rates with the 10 t/ha phospho-compost rate producing the highest grain yield of 484.36 kg/ha. This has economic implications on the farmer, since the lowest phospho-compost rate provided the highest yield (Akande et al., 2015). Thus, for soil amendment, it would be advisable for the farmer to use the 10 t/ha rate as an organic fertilizer for the production of cowpea. Although Adediran et al. (2015) reported that the optimum rates of organic fertilizers for sustainable maize and cowpea yields were between 5 and 10 t/ha, which is in agreement with the current study, grain yields obtained seemed exceptionally low. This could be the result of the undesirable negative consequences of possible high doses of the pre-emergence herbicide used on the field. The application of a mixture of Paraquat and Dual gold combination as pre-emergence herbicides exerted phyto-toxicity effect on cowpea, thus resulting in delayed seedling emergence as well as suppressed plant growth.

The higher grain yield obtained under minimum (611.66 kg/ha) than conventional (359.06 kg/ha) tillage agrees with earlier observations by Mupangwaa et al. (2012) who found that reduced tillage systems provided more grains than the conventional system. The range of 10.79 to 11.88 for the mean number of seeds per pod could be compared to the value of 13.00 reported by Gerrano et al. (2015) but higher than those reported by Idahosa et al. (2010). The range of 17.48 to 18.07g for the 100-seed weight obtained in this study is comparable to the 7.79 to18.67g ranges found by Gerrano et al. (2015).

The detected higher increase in total P content of cowpea plant tissues with inorganic P fertilizer amended soil than the higher rates of phospho-compost at both nodulation and postharvest contradicts the findings of Bulluck et al. (2002) who reported higher improvements in the soil physical, chemical and biological attributes in compost amended than synthetic fertilizer amended soils. The observed increase in soil total C content, following increase in compost rates, agrees with earlier findings by Evanylo et al. (2008) who reported that high compost rate treatments increased soil C. The slightly higher total P content in cowpea plant tissue at postharvest under dryland conditions could be attributed to possible better nutrients absorption from the soil over their growth period.

The postharvest of cowpea grains and the soil samples revealed a high concentration of Aluminium (Al) and Iron (Fe) possibly emanating from the use of high doses of a mixture of Paraquat and Dual gold as pre-emergence herbicides. The high concentrations of Al and Fe had a detrimental effect on the growth of cowpea, particularly during the early stages of plant development by affecting the physiological processes of the plant. This is supported by Feng (2005) who found that high metal levels impede plant growth, thus affecting physiological processes. Fe is required most biological systems, however excessively high concentrations of Fe and Al results in plant toxicity as observed in the current study with acceptable threshold concentrations exceeded (Dimpka et al., 2009).

4.6 Conclusion

The use of low-input technology as components of improved agricultural practices for sustained production could go a long way towards achieving food security. The results of this study showed that cowpea growth parameters significantly increased with sampling dates. Tillage and the different phospho-compost rates significantly influenced all cowpea growth parameters except the chlorophyll content. The 10 t/ha phospho-compost rate provided the highest cowpea grain yield among the phospho-compost rates while minimum tillage also resulted in higher grain yields. Cowpea nodulation was also better under minimum tillage.

4.7 References

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CHAPTER 5: GENERAL SUMMARY AND CONCLUSION

The results obtained in this study emphasized the fact that cowpea could be grown successfully using low input agricultural practices. Phosphorous (P) is one of the macro-nutrients that is very important to crop production and this is no different even for cowpea, which also requires P in large quantities, particularly during the early stages of plant development. South African soils are characterized by low P availability that poses a major problem towards sustainable crop production. This situation is very prevalent among smallholder farmers who cannot afford chemical fertilizers. The use of phospho-composts thus, provides them with an ideal alternative to enhance crop productivity and improve their soil at the same time. The application of phospho-compost could help increase the P content considerably, thus improving the fertility of the soil, which will further supply nutrients to the plants. P released from GPR is a challenge due to its non-reactive nature. As such, it cannot be directly applied to the soil, the composting process helps solubilize the GPR and helps accelerate the release of P.

The aim of the study was to investigate the impact of low-input agriculture practices on grain cowpea productivity under tunnel house and dry land field conditions. This this was achieved with the help of two tunnel house trials and one field trial, which were monitored from the planting to harvesting stages. The study also sought to evaluate the ability of cowpea to withstand and produce under moisture stress conditions. Two moisture regimes were used under tunnel house conditions, which were later tested under dry land conditions, characterised by water scarcity. This was done to evaluate the drought tolerance ability of the variety of cowpea grains (white seeded cowpea) to test whether it could be productive when moisture deprived. Most farmers in South Africa, particularly smallholders, grow their crops under dry land conditions, thus necessitates drought tolerant crops. The result obtained revealed cowpea to be a crop that can withstand moisture stress and that is ideal for farmers under dry land conditions. There is need for farmers to reduce using chemicals such as herbicides and pesticides, which could have a significant effect on the physiological processes of the cowpea. It was observed during the field trial that the use of these chemicals could increase the level of heavy metals, which could be toxic to the plants and, subsequently, affect the productivity of the crop. The high levels of Al and Fe found in the soil contributed significantly to the low cowpea yields that were ultimately recorded.

In conclusion, the results obtained from the three trials and the subsequent laboratory analyses revealed that the application of phospho-compost can be of agronomic importance by supplying P and N to the soil. Generally, soil N and P increased with a rise in phospho-compost application rates. The application of 40 t/ha compost rate, however, seemed to enhance the productivity of cowpea as it produced the highest seed yield under tunnel house trial 2 and the second highest grain yield in tunnel house trial 1 and the field trial. Under dryland crop thrived under minimum tillage compared to conventional tillage, which can only be beneficial to the farmer. Conventional tillage has some drawbacks (as it comes with high labour and fuel costs), which could cost the farmer a lot of money. Another disadvantage of conventional tillage is that it also breaks the soil structure that promotes soil erosion, thus ultimately affecting the soil quality. The practice is also unsustainable since it degrades the soil over time, which is the most critical natural resource in agriculture. Thus, the reason why minimum tillage is a much better option when growing cowpea. Under tunnel house conditions, cowpea seemed to favour the Coega and the Glenrosa soil type compared to the Hutton soil type but, in general, cowpea proved that it can adapt to variable conditions and it could be productive under low input agricultural practices.