Improving dry land maize (*Zea mays*) productivity through crop rotation with cowpeas (*Vigna unguiculata*)

by

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DECLARATION

I hereby declare that this thesis, prepared for the MSc. Agric (Agronomy) degree, which was submitted by me at the University of Pretoria, is my own work. This work has not been submitted for any degree to any other university.

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LIST OF ABBREVIATIONS

CV	Coefficient of variance
cm	Centimetre
g	Gram
ha	Hectar
ha^{-1}	Per hectar
K	Potassium
P	Phosphorus
kg	Kilogram
KNC	Kernel number per cob
m	meter
N	Nitrogen
SAS	Statistical Analysis System
%	Percentage
DMY	Dry matter yield

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ABSTRACT

Improving dryland maize (Zea mays) productivity through crop rotation with cowpeas (Vigna unguiculata)

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Maize is the most important cereal crop grown in areas of South Africa by both small-scale and commercial farmers. Maize monocropping without sufficient input and declining soil nitrogen content are some of the factors that limit yield. The objective of the study was to evaluate the effect of different cowpea cultivars and populations on growth, yield and yield components of succeeding maize. The effects of cropping systems on soil N content were also observed. Field experiments were conducted during the 2005/2006 and 2006/2007 growing seasons at Potchefstroom and Taung in North West province. The trial consisted of four cowpea cultivars: PAN 311 (short duration cowpea cultivar), CH 84, Bechuana white (medium duration cowpea cultivar) and TVU 1124 (long duration cowpea cultivar) and, four planting densities (10 000, 15 000, 20 000 and 40 000 plants ha^{-1}). Maize was used as sequential test crop to determine the residual effect of previous cowpea treatments. Cowpea grain yield increased as planting density increased at both localities. TVU 1124 gave highest grain yield of all cowpea cultivars at both localities. Total dry matter yield also increased with increasing planting density. After cowpea soil NO_3^- and NH_4^+ content increased with increasing density. Similarly, soil NO_3^- content of maize following cowpea showed a considerable improvement, compared to maize monocropping. The highest soil NO_3^- and NH_4^+ content was observed when maize followed Bechuana White. Significant differences were also observed in soil microbial activities among the cultivars. Maize grain yields and plant height responded positively to the previous cowpea crop, compared with maize monocropping at both locations, but especially at Taung. Maize stover yield, cob length and KNC significantly responded to maize and cowpea rotation compared to maize monocropping at Taung. These results further confirm the potential of using cowpea to contribute soil N to subsequent maize crops in a rotational system.

Keywords*:* sequential-cropping, monocropping, planting density, cowpea, maize, yield.

GENERAL INTRODUCTION

Sequential cropping refers to the growing of two or more crop species in sequence on the same field per year (Ricardo, 2000). This is also referred to as crop rotation which is a practice to improve or even ensure sustainable crop production through its effect on soil nitrogen fertility, diseases and crop yield (Willey *et al*, 1982). Typically, cereal-legume combinations such as maize and cowpea are associated plant species.

Rotation of cereals and legumes is usually preferred to sole cropping of either crop because yields are higher (Baldock *et al.,* 1981) and production costs are lower. Improved management practices are therefore, needed to help farmers to improve economic profitability, while conserving resources. Cultivation of leguminous crops in rotation with other food crops has been recognized as one of the most cost effective ways by which farmers can maintain soil fertility (Osunde *et al.,* 2003).

Cropping systems can be used as alternative to the use of plant residues to maintain soil fertility. This is because soil fertility decline is a critical concern to farmers. Research has found that the organic matter content of South African soils under dry land cultivation is decreasing (Du Toit *et al*., 1994). Numerous published results state that organic inputs are needed to improve soil physical, chemical and biological properties. Therefore, growing several species of crops together or sequentially may utilize nutrients more efficiently than monoculture if the different species exploit a larger soil volume or different parts of the profile (Frencis, 1989).

Nutrient deficiencies, especially of the major nutrients (N and P) are among the major constraints to crop production. This problem could be solved by using chemical fertilizers, which are inaccessible to most of the resource poor farmers because of their high cost. However, small-scale farmers are resource-constrained and the incorporation of N- fixing legumes, whether used in sequential or intercropping with cereals crops, is a possible solution to the N problem (Elowad & Hall, 1987). In areas where monocropping is practiced mainly by the small-scale farmers, soil fertility and crop yields decline rapidly if nutrients are not supplemented.

Maize (*Zea mays* L.), which is a cereal, is an important grain crop and is produced throughout under diverse environments. Cereal production depends on the application of production inputs that will sustain the environment and agricultural production, and is needed to sustain good yields (Jeranyama *et al*, 2000). Maize yield decline under continuous cultivation has been attributed to loss of organic matter and soil compaction, which subsequently leads to poor soil moisture relations and low soil nitrogen content (Juo *et al*, 1995). Therefore, the declining maize yield need to be improved for more sustainable production systems by providing additional nitrogen to the cereal crop through legumes (Papastylianou, 2004).

The use of organic inputs such as leguminous green manure and crop residues could be an alternative for maintaining soil fertility and sustain crop yields (Zoumane *et al.,* 2000). Maintenance or improvement of soil fertility has been a focus of many research projects in smallholder farming systems in Southern Africa (Chikowo *et al.*, 2004). The findings were that the development and adoption of summer crop legumes in rotation with maize or as intercrop with other cereals may enhance soil fertility, reduce fertilizer inputs and improve productivity.

Cowpea (*Vigna unguiculata*) is a summer-grown, drought and heat tolerant tropical legume crop and is an excellent quality crop for human consumption, both as vegetable and grain. It is cultivated for its seed, pods and/leaves, which are consumed in fresh form as green vegetables. It also produces high quality and quantity herbage for animal feed (Duke, 1983). Cowpea also has the ability to be intercropped with cereals such as millet and sorghum. Its diversity of uses, nutritive content and storage qualities have made cowpeas an integral part of the farming system in the West African region (Eaglesham *et al.,* 1992). However, most of the cowpeas are grown primarily in dry regions where drought is prevalent among several yield-reducing factors. Cowpea is also very important for improved soil fertility, soil conservation and sustainability of various cropping systems.

Legumes are used commonly in agricultural systems as a source of atmospheric N through symbiotic N_2 fixation for subsequent crops, maintaining soil nitrogen levels and through subsoil retrieval (Gathumbi *et al.,* 2002). Cowpea, as a legume also produces nitrogen through fixation of atmospheric nitrogen by bacteria in nodules of their roots (Hesterman *et al*, 1987). It can be grown in nitrogen-impoverished soil without fertilizer inputs. Therefore, it is beneficial to alternate cowpea with cereals and other plants that require nitrogen.

The ability to form this symbiosis reduces fertilizer cost for farmers that grow legumes, and legumes can be used to replenish soil that has been depleted of nitrogen (Baruddin & Meyer, 1984). This use is particularly important where nitrogen fertilizer often is not economically feasible due to poor market and infrastructure development (Glasener *et al*., 2002).

The amount of N_2 fixation by legumes is affected by soil fertility, in particular by the presence of mineral nitrogen (Papastylianou, 2004). Increased yields of cereals after legume are reported to depend on the level of soil nitrogen. This increase in maize yields may be due to lower or higher microbial activities (Turco *et al.*, 1990). There are research results that indicate that yields obtained after legume production are higher than those ascribed to the added nitrogen supply alone (Hargove, 1986).

Though the beneficial effect of legumes has been recognized, the mechanism by which a legume benefits its subsequent crop remains unclear. Presently studies have been conducted to quantify the legume nitrogen contribution to subsequent crops and have dealt with above ground legume nitrogen, ignoring root nitrogen because of the difficulty in harvesting roots and nodules (Glasener *et al.,* 2002).

Nitrogen fixed by legumes in the preceding season might increase the yield of maize. Therefore the objective(s) of this study were to evaluate the effect of different cowpea cultivars and populations on succeeding maize growth, yield and yield components.

The following hypotheses were tested:
1. The introduction of cowpeas in a maize cropping system will increase maize yields compared to maize mono-cropping.

2. Higher cowpea population will result in higher soil residual N levels, which will benefit the succeeding maize yields more.
3. Longer duration cowpea cultivars will result in higher soil residual N levels.
4. Cowpeas in a maize crop rotation will reduce the need for inorganic fertilization on subsequent maize.

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CHAPTER 1: LITERATURE REVIEW

1.1 Cowpea background

Cowpea (*Vigna unguiculata* L Walp) is one of the most widely adapted and nutritious grain legumes grown in warm and hot regions of the world.Cowpea belongs to the Fabaceae family. Cowpea has several common names. In English cowpeas are commonly known as Bachapin beans, Black-eyed pea, Southern crowder pea, China pea and Cowgram; in Afrikaans: Akkerboon, Swartbek boon and Koertjie. In Limpopo province cowpea is commonly known as Munawa; in Venda, Indumba and Dinawa in Northern Sotho (NDA, 1985). Summerfield *et al.* (1974), describe cowpea as an annual herb reaching heights of up to 80 cm, with a strong taproot and many spreading lateral roots in the surface soil. Its growth forms vary and many are erect, trailing, climbing, or bushy, usually indeterminate growers under favorable conditions.

Cowpea plants are tolerant to drought and acid soil, and their ability to fix atmospheric nitrogen contribute to their fast growth habit in tropical climates characterized by low rainfall, high temperatures and soil with low fertility (Ehlers & Hall,1997). Being a drought tolerant crop, it is well adapted in areas where other food legumes do not perform well, and grows well even in poor soils with more than 85% sand, less than 0.2% organic matter and low levels of phosphorus.

Grain legumes are grown on very small portions of the land on smallholder farms, and though N_2 fixation rates can be high, overall farm N inputs from biological N_2 fixation are in some cases as low as 5kg farm^{-1} year^{-1} as the area planted to legume is often small (Giller, 2001). In Africa cowpea is cultivated under diverse soil and climatic conditions and it is mostly intercropped or rotationally grown with cereals such as millet, sorghum and maize.

1.2 Maize background

Maize is of the family Gramineae and originated in the Tropics of Latin America. It is the world's most widely grown cereal and is ranked third after wheat and rice, in terms of production. Its production is widely distributed (Ayisi & Poswall, 1997). In South Africa, the crop occupies about four millions hectares of the country's arable land and about one third of South African farmers are maize farmers (Van Rensburg, 1978). Approximately 8, 0 million tons of maize grain is produced in South Africa annually on approximately 3, 7 million ha of land (Du Plessis, 2003). Dry land maize production in South Africa varies from year to year depending on the amount and distribution of rainfall. Yield reduction in most dry land maize growing areas is due to erratic seasonal rainfall distribution (Du Toit *et al.,* 2002). Water availability is specifically the most limiting factor of dry land maize production in South Africa (PECAD, 2003).

In intercropping systems, maize is commonly grown with cowpeas, groundnuts, watermelons, sweet sorghum, squashes and pumpkins. Despite its importance in South Africa, the productivity is still marginal on smallholder farmer's fields, even in situations where farmers have access to irrigation (Modiba, 2002). Successful maize production depends on the correct application of production inputs that will sustain the environment as well as agricultural production. These inputs are adapted cultivars, planting density, soil tillage, fertilization, weeds, pest and disease control, harvesting, marketing and financial resources.

1.3 Cropping systems

Sole cropping, intercropping and rotations of legumes and cereals are dominant cultural practices in Africa. Cereal-legume cropping systems also benefit the subsequent crop through non N benefits such as (1) reduced incidence of root and leaf diseases in subsequent crops (Cook, 1992; Smiley *et al.,* 1994), (2) reduced weed populations, (3) increased P, K and S availability (Stone and Buttery, 1989), (4) ameliorated soil structure (Badruddin & Meyer, 1994) and (5) release of growth substances from legume residues (Fyson & Oaks, 1990). The mineral N in the root zone soils is often higher in cereal-legume cropping systems than cereal monoculture (Evans *et al.,* 1989; Dalal *et al.,* 1998). Symbiotic N fixation plays a key role in these cropping systems and a right combination can bring benefits in N status of both legumes and non legumes (Nambiar *et al.,* 1982; Crookston *et al.,* 1991).

Cropping systems benefit from the accumulation of N if a major proportion is derived from the atmosphere or from deep in the soil profile. Root distribution patterns vary with species observed having a deeper root system than several other legumes (Purseglove, 1968). N return to the soil is affected by the quality of crop residues. Leguminous crop residues often decompose more quickly than cereal residues due to lower C/N composition, but the amount of crop residue that reverts to the soil is often higher for cereals than for legumes (Primavessi, 1984). Therefore, incorporating legumes into the cropping system provide N enrichment into the soil.

1.3.1 Crop rotation

Crop rotation is the practice of growing two or more crops in the same space in sequence or a definite sequence of crops grown in successive years (or successive seasons) on the same land, the sequence being repeated again and again. According to El Titi *et al.* (1993), crop rotation can produce good quality outputs in an environmentally friendly way and ensure the sustainable production of healthy, good-quality crops. Therefore, crop rotation can minimise pests by maintaining good biological diversity in the agro-ecosystems, giving priority to the use of natural regulating mechanisms and preserving long-term soil fertility.

Crop rotation can maintain soil fertility by improving soil structure and by enhancing soil quality as crop residues improve the quality of the soil organic matter, particularly with regard to leguminous plants that add nitrogen (Eltz & Norton, 1997). Crop rotation also allows natural processes in the soil to take place by helping to break the cycle of harmful organisms affecting crops. In this cropping system, soil is less vulnerable to erosion as rotations, which include root crops and cereals which can reduce losses by up to 30%, compared with sole cropping systems (Stone & Buttery, 1989).

Crop rotation is usually superior to both monoculture and intercropping as yields of sole cropped and intercropped maize were found to be only 35% and 38%, respectively, of yields from crop rotation in the African savanna. Thus, rotational cropping involving legumes and cereals is a more susceptible system for increasing food production in Africa than intercropping (Dakora & Keya, 1996).

The improved soil conditions are likely to enhance the productivity of both legume and cereal phases. Returning residues to the soil may also moderate extremes the rotation but legume N_2 fixation and N balance as well (Shah *et al.,* 2003). Several combinations of legumes and non-legumes may be used in multiple cropping systems, rotation or intercropping to contribute to the regenerative processes that must operate in a sustainable system (Bohlool *et al.,* 1992).

1.4 Nitrogen importance and its contribution by legumes in a rotational system

Nutrient elements are not readily available for plant use. They become available for plant use through mineral weathering and organic matter decomposition. Nitrogen (N) nutrition is an important determinant of the growth and yield of maize. N fertilizer must be used judiciously to maximize profit, reduce the susceptibility to diseases and pests, optimize crop quality, save energy and protect the environment (Schroder *et al.,* 2000).

Nitrogen limitations on maize productivity in smallholder farming systems in Southern Africa are widespread and endemic (Robertson *et al.,* 2005). As fertilizer prices rose, organic sources of fertility became an increasingly important option for increasing soil fertility and maize yield (Palm *et al.,* 1998). The amount of N_2 fixed and the N contribution from leguminous crops are influenced by a number of environmental factors including soil type, nutritional status of soil, species and varieties, climate as well as management of crop residues (Ledgard & Steele, 1992; Rao & Mathuva, 2000).

Among the plant nutrients, nitrogen plays a very important role in crop productivity and its deficiency is one of the major yield limiting factors for cereal production (Shah et al., 2003). N deficiency is frequently a major limiting factor for high yielding grain crops in the tropics. The extent of the deficiency depends on many factors including inherent soil fertility, whether the crop is a legume or non-legume, the cropping system or rotation employed and the skills of the producer (Date, 2000).

Success of a legume crop to N contribution to succeeding crop depends on the capacity to form effective nitrogen fixing bacteria. In many farming systems the use of leguminous green manures is traditional, and the inputs from BNF often promote significant increase in subsequent grain or other crops (Ramos *et al.,* 2001).

Plant residues decomposing in soils is the most important source of N for plant growth in natural ecosystems, with the exception of those dominated by N_2 –fixing plants. The environmental concerns related to the use of mineral fertilizers have raised new interest in nutrient recycling through plant residues in agriculture (Ehaliotis *et al.*, 1998). Research studies have shown that regular and proper addition of organic materials (crop residues) are very important for maintaining the tilth, fertility and productivity of agriculture and controlling wind and water erosion, and preventing nutrient losses by run-off and leaching (Lal *et al.,* 1980; Bukert *et al.,* 2000).

The release of N from decaying plant residues has been clearly related to their structural and chemical characteristics (the residue quality), to biotic activity and abiotic characteristics of the soil environment (Jenkinson, 1981). The total amount of N released from high quality legume residues during the first cropping season is large. Up to 70% of legume N is released in temperate systems and even higher amounts under tropical conditions (Giller & Candisch, 1995). Legume residues, because of their quality (e.g. low C: N ratio), can decompose fast with residual soil moisture or after early rains. Returning residues into the soil may also moderate extremes of soil temperatures, improve soil organic matter levels, soil structure, infiltration storage and utilization of the soil (Doran *et al.,* 1984 & Power *et al.,* 1986).

Removals of crop residues will decrease the amount of organic matter returned to the soil and may adversely affect the accumulation of carbon and N in the soil over a long term. Therefore, concern for the sustainability of yield and soil fertility has led to a renewed interest in crop rotation, including legumes and retaining crop residues. Returning crop residues after harvest is one way to improve water conservation and storage as well as stabilize soil fertility and crop yields (Shafi *et al.,* 2007). Organic compounds help to improve soil by increasing water retention capacity, thus impeding nutrient loss by leaching, by decreasing erosion and surface drainage, and by helping control weeds and other pests (Anaya *et al.,* 1987).

1.5 Benefits of legumes in a cropping systems

The benefits from legumes in cropping system have been attributed to nitrogen contribution to subsequent crops and to other improvements in soil properties. Increased yields of cereals after legume are reported. This may be due to increased microbial activities (Turco *et al*, 1990). Though the beneficial effect of legumes has been recognized, the mechanism by which a legume benefits its subsequent crop remains unclear. Presently studies have been conducted to quantify the legume nitrogen contribution to subsequent crops and have dealt with above ground legume nitrogen, ignoring root nitrogen because of the difficulty in harvesting roots and nodules (Glasener *et al* 2002). Legumes may contribute to weed suppression and breaking of cycles of cereal pest and diseases, and phytotoxic and allelopathic effect of different crop residues.

1.5.1 Biological nitrogen fixation (BNF)

Biological nitrogen fixation (BNF) is the process that changes inert N_2 to biologically useful NH_3. This process is mediated in nature only by bacteria. Other plants benefit from nitrogen fixing bacteria when the bacteria die and release N to the environment or when the bacteria live in close association with the plants. In legumes and a few other plants, the bacteria live in small growth on the roots called nodules. Within these nodules, bacteria do N fixation, and the plant absorbs the NH_3 produced. N fixation by legumes is a partnership between a bacterium and a plant (Liedemann & Glover, 2003).

When legumes are used in cropping system, N availability in the soil may increase as a result of two effects. Firstly, the conservation of soil N through N_2 fixing legumes in comparison to non- fixing plants (Giller & Wilson, 1991). Secondly, the enhanced mineralisation of soil organic nitrogen during the decomposition of legume residue ‘primary effect’ (Jenkinson *et al.,* 1985). The use of rotational systems involving legumes for N_2 fixation benefits is important because of sustainability considerations. This nitrogen may be either released throughout the growing season as roots and nodules die or sloughed off or as exudates or during the decomposition of roots after harvest (Crawford *et al.,* 1997; Jensen, 1996).

The net amount of symbiotically fixed nitrogen in legume residue returned to the cropping system depends on the amount of symbiotic activity, the amount and the type of residue left in the soil and the availability of soil-N to the legume (Hargove, 1986). Haynes & Beare (1997) suggest that some legume roots deposit material of higher nitrogen content, which enhances aggregate stability through greater exploration of those aggregates by fungal hyphae.

1.5.2 Improving and maintaining soil nutrients

Legumes can play a role in the maintenance of soil productivity in low input farming systems through N_2 fixation. The legumes meet some of their N requirements through N_2 fixation and increase plant-available nitrate N in the soil (Giller *et al.,* 1991). The higher concentrations of soil nitrate result from conservative use of nitrate by the preceding legume crop (nitrate sparing) coupled with the release of mineral N from legume residues and nodules (Herridge *et al.,* 1995; 1995; Dalal *et al.,* 1998). Soil fertility improvement and pest control are ancillary benefits from legume-cereal rotation or mixing crops with unrelated growth characteristics.

Legumes can improve the nutrient status of the soil. Reduced tillage with crop residue retention offers great potential to increase water available to the crop and reduce erosion (Lal, 1989). Soil fertility decline has been described as one of the causes of declining food production. It has resulted due to continuous nutrient mining without sufficient external input for soil fertility replenishment and unsuitable production systems.

Soil organic matter is critical to sustainable agricultural productivity in tropical regions, especially in savannah ecosystems. It is an important factor affecting soil quality and long- term sustainability of agriculture (Doran & Parkin, 1994). The use of legumes to improve soil nitrogen and cereal yields have been widely reported for a large number of agricultural production systems (Toomsan *et al.,* 1995). The use of organic inputs such as leguminous green manure and crop residues could therefore be an alternative for maintaining soil fertility.

Maintaining and improving soil quality is crucial if agricultural productivity and environmental quality are to be sustained for future. Legume crops do not improve only the nutrient status of the soil but also produce the greatest improvement in soil aggregation and stability by the most extensive root development (Stone & Buttery, 1989). Thus, legume crops should be considered for improving poorly structured soils. This is because the rotation of legumes and cereals may restore soil organic matter levels.

Numerous published research results have shown that organic inputs are needed not only to replenish soil nutrients but also to improve soil physical, chemical and biological properties (Zoumana *et al.,* 2000). It is now recognized that significant amount of crop legume nitrogen can be present below ground (Russel & Fillery, 1996). According to Armstrong *et* *al.,* (1999), perennial legumes had a more beneficial effect on soil chemical and physical properties than annual legumes.

Grain legumes contribute less nitrogen than herbaceous legumes to subsequent crops in rotation (Giller *et al*., 1997), because most of the N fixed biologically by grain legume is translocated to grain and both the grain and residues are invariably removed from fields for human and livestock use (Rao & Mathuva, 2000). The full benefits of legumes will be only being realized, however, if all residues are returned after grain harvest (Jensen, 1995).

Sustainable agriculture seeks to provide the needs of the present without compromising the potential in the future. Therefore, practices that produce sustainable yields and economic returns at the same time enhance and maintain soil quality, are preferred over those that degrade the soil as a resource base (Ferreira *et al.,* 2000). An essential element of agricultural sustainability is the effective management of N in the environment. This usually involves the use of biologically fixed N_2 because N from this source is used directly by the plants, and is thus less susceptible to volatilization, denitrification and leaching (Graham & Vance, 2000). In the agricultural setting, 80% of this biologically fixed N_2 comes from symbioses involving leguminous plants and species of *Rhizobium, Bradyrhizobium,Azorhizobium*, *Mesorhizobium* and *Allorhizobium* (Vance, 1998).

Legumes can play a role in the maintenance of soil productivity in low-input farming systems through N_2 fixation, recovering of deep nutrients and addition of organic material to the soil. Soil organic matter (SOM) dynamics and maintenance in agricultural systems have received considerable attention due to their role both in sustainable agroecosystem functioning and global carbon dynamics. By contributing greatly to a number of soil properties, SOM is fundamental in maintaining fertile and productive soils (Tiessen *et al.,* 1994; Craswell & Lefroy, 2001).

Legumes are used to improve short-term fallows as they offer additional potential benefits as forage and as components of conservation tillage system (Wortmann *et al.,* 2000). Legumes have long been advocated as the missing ingredient for conserving soil resources in subsistence agriculture (Thapa, 1996). These include green manures and legume intercropping or rotations. Experiments have shown that these systems can enhance soil productivity through biologically N fixation, carbon inputs and conservation of nutrients (Snapp *et al.,* 1998).

Greenland (1975) suggests five basic principles of soil management essential for sustainable agricultural production. He suggest that chemical nutrients removed by crops must be replenished; the physical condition of the soil must be maintained; there must be no build up of weeds, pest or diseases and there must be no increase in soil acidity or toxic elements and soil erosion must be controlled to be equal to less than the rate of soil genesis.

1.6 Uses and benefits of cowpeas in cropping systems

Cowpea is a large seeded legume grown for its protein rich pods, grains and stover by resource poor farmers of under developed and developing countries of Africa and Asia. Cowpea makes a valuable contribution towards human food and livestock fodder during dry periods when animal feed is scarce (Singh & Tarawali, 1997). It is a dual-purpose crop that makes it a very attractive crop where land is becoming scarce (Singh *et al.,* 2003). Cowpea can be used at all stages of growth as a vegetable crop. Leaves are an important food source in Africa and are prepared as a potherb, like spinach. Grains of cowpea are an important source of protein. Cowpea grains contain an average of 23% to 25% protein and 50% to 60% carbohydrates (Quin, 1997).

Cowpea is one of the most widely adapted, stress tolerant, indigenous and nutritious grain legumes in warm to hot regions of Africa, Asia, and America (Ehlers & Hall 1997). In West Africa, cowpea haulms are used as a fodder, mature cowpea pods are harvested and the haulms are cut whilst still green and rolled into small bundles containing leaves and vines (Tarawali *et al*., 1997a,b).

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CHAPTER 2: MATERIALS AND METHODS

2.1. Location

Field experiments were conducted under dry land conditions during the 2005/06 and 2006/07 planting seasons at two different locations, namely ARC-GCI Potchefstroom and Taung Provincial Department of Agriculture experimental farm. Both Taung and Potchefstroom are located in the North West Province of South Africa. Taung is located at 27^0, 32' S; 24^0 48'E and 7000m altitude, while Potchefstroom is located at 26^0 43'S; 27^0 06'E and 1347m altitude. At Potchefstroom plantings were done on the 09 December 2005 and 21 November 2006, while the trial at Taung was planted on 12 December 2005 and 23 November 2006.

2.2. Soil characteristics

The soil type at Potchefstroom is classified as a Hutton form soil, while Taung soil was a sandy Avalon. Selected soil properties of these locations appear in Table 2.1.

Table 2.1 Pre- plant chemical and physical soil properties at Potchefstroom and Taung

		Chemical analysis	
	Depth (cm)	Potchefstroom	Taung
pH (KCl)	0-15	6.3	5.9
	15-30	6.4	6.1
	…………………… (mg/kg)………………………		
P (Bray 1)	0-15	16.7	9.6
	15-30	9.7	4.3
K	0-15	119.3	108.7
	15-30	91	95.3
Ca	0-15	1220	358
	15-30	1290	351.3
Mg	0-15	528	107
	15-30	586.3	106
Na	0-15	39.3	24.7
	15-30	52.6	25.3
Total N	0-15	9.7	9.3
	15-30	7.3	3.3
	……………Physical analysis (%)…………………		
Sand	0-30	48.7	88.8
Silt	0-30	17.3	4.34
Clay	0-30	34	4.49

2.3 Climate

At Potchefstroom during the 2005/06 planting season, rainfall increased from January to March compared to the other months as well as long term averages (Fig 2.2). In the 2005/06 planting season, rainfall was higher, compared to the 2006/07 planting season. The rain at Taung was evenly distributed in 2005/06 and 2006/7 compared to the long-term average rainfall. Taung received the highest monthly rainfall (92mm) during the 2005/06 season in March, when compared to 2006/07 as well as the long-term averages (Fig. 2.1).

At Potchefstroom during the 2005/06 season, the minimum temperatures ranged from 0.6 ^{0}C to 17.7, while in the 2006/07 season minimum temperatures ranged from 0 ^{0}C to 16.5 (Table 2.2). The maximum temperatures during the 2005/06 seasons ranged from 19.9 ^{0}C to 30.3 ^{0}C, while the 2006/07 season maximum temperatures ranged from 19.4 ^{0}C to 31.2 ^{0}C. At Taung the minimum temperatures during the 2005/06 seasons ranged from 0.1 ^{0}C to 12.9 ^{0}C while the 2006/07 season minimum temperature ranged from 1.6 ^{0}C to 16.0 ^{0}C (Table 2.3). The maximum temperatures during the 2005/06 seasons ranged from 20.1 ^{0}C to 32.2 ^{0}C, while during the 2006/07 season maximum temperatures ranged from 19.2 ^{0}C to 33.7 ^{0}C.

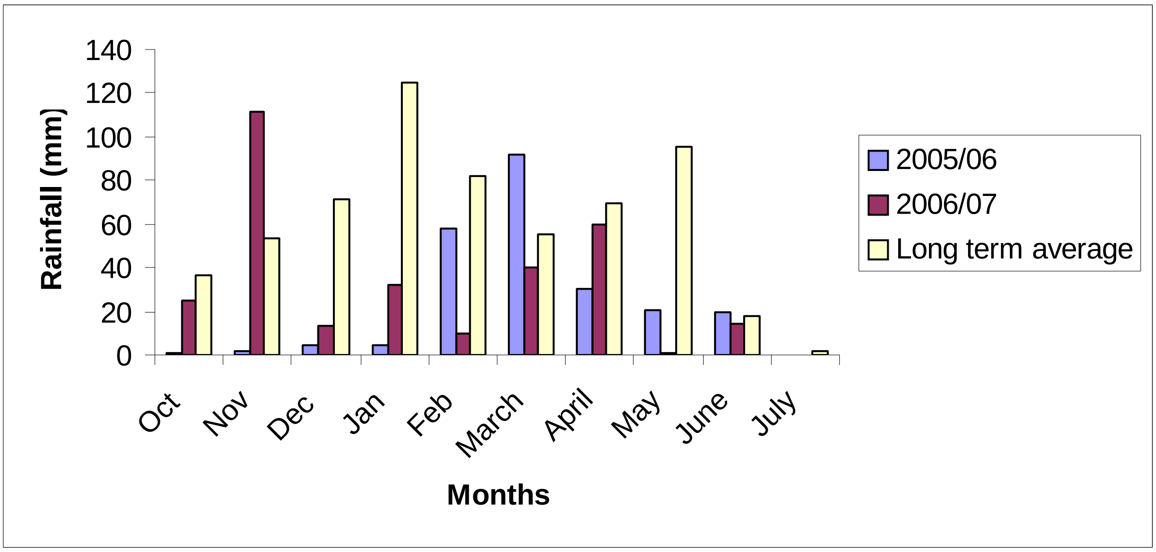

Fig.2.1 Monthly rainfall (mm) from October to July during 2005/06 and 2006/07 growing seasons compared to the 10 year long term averages at Taung.

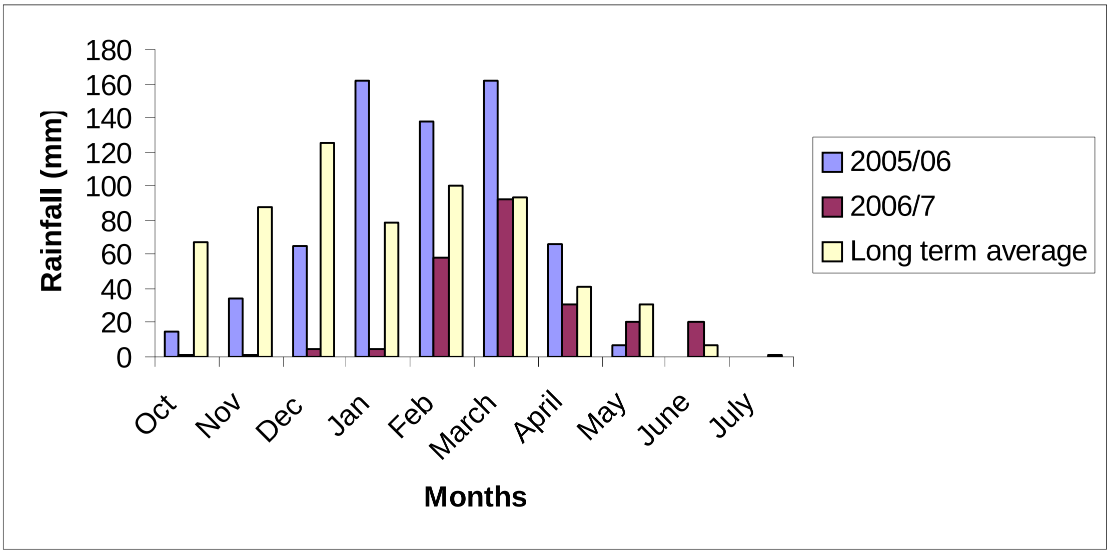

Fig.2.2 Monthly rainfall (mm) from October to July during 2005/06 and 2006/07 growing seasons compared to the 10 year long term averages at Potchefstroom.

Table2.2 Mean monthly maximum and minimum temperatures during the 2005/6 and 2006/07 growing seasons compared with the 10 year long term averages for Potchefstroom

	2005/6 Season		2006/07 Season		Long-term averages	
Months	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C
October	29.8	13.2	28.7	12.8	28.1	12.3
November	30.3	14.4	28.4	14.2	28.1	13.8
December	30.3	15.7	29.7	16.5	28.7	15.3
January	27.7	17.7	30.8	16.0	29.1	15.9
February	27.1	17	31.2	15.2	28.7	15.9
March	24.8	13.7	29.5	13.4	27.4	14.1
April	23.8	10.2	25.5	10.6	25.2	10.1
May	19.9	2.9	22.8	2.6	21.8	4.9
June	19.9	0.6	19.4	1.2	19.8	1.3
July	21.8	2.9	19.5	0.0	19.4	0.8

Table2.3 Mean monthly maximum and minimum temperatures during the 2005/06 growing season compared with the 10 year long term averages for Taung

	2005/06	Season	2006/07 season		Long-term averages	
Months	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C
October	29.2	10.1	29.5	10.3	28.9	10.1

November	31.0	11.6	30.4	12.7	30.4	12.6
December	32.2	12.4	32.3	14.9	31.4	14.8
January	29.1	9.8	33.1	16.0	31.1	16.6
February	27.0	9.7	33.7	14.0	31.0	17.0
March	26.8	12.9	30.9	11.8	29.8	14.9
April	25.2	8.5	26.8	10.3	26.5	9.4
May	20.6	1.7	23.6	1.8	23.0	3.6
June	20.1	0.1	19.2	-0.1	20.5	0.5
July	21.5	1.4	20.0	-1.5	20.2	-0.1

2.4. Experimental design and treatments

The experiment consist of four cowpea cultivars, four planting densities and maize as rotational crop arranged in a randomized block design with three replications. The treatments were cowpea cultivars (Pan 311, Bechuana White, TVU 112 and CH 84) and planting densities (10 000, 15 000, 20 000 and 40 000 plants ha^{-1}). Maize was used as test crop to determine the residual effect of previous cowpea treatments as shown in Fig.3. The cultivar used for maize was PAN 6479. Plots were 6m x 4m in size each. Two cropping systems were established simultaneously: (1) a cowpea-maize rotation and (2) continuous maize. The middle three rows of both cowpea and maize crops were harvested, leaving one side row as border rows. At Potchefstroom during the 2006/07 planting season pre-plant weed control was done with Gramoxone while at Taung no herbicide was applied. All the plots at both locations were planted manually. All cowpea cultivars were inoculated with Akkerbonepak®50, which contains a combination of *Rhizobium,* rhizosphere organisms and micronutrients, at the rate of 700ml per 50 kg seed before planting.

The remaining cowpea vegetative parts were incorporated into the soil to provide residual N. After a period of 3-4 months between crops, the same plots were prepared for maize according to the cropping sequence. A continuous maize monocropping sequence was prepared at the same time as the cowpea-maize rotations. All maize was planted at 100cm between rows and 30cm within rows for all plots.

Plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cowpea cultivars	A	A	A	A	A	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D
Density	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4

Fig. 3 The experimental layout showing arrangement of treatments of cowpea varieties and maize at Taung and Potchefstroom.

Cowpea cultivar A stand for CH 84, B for PAN 311, C for TVU 1124 and D for Bechuana White. For 0 (e.g. plots 1, 6, 11 and 16) only maize was planted on plots at 33000 plants $^{-ha}$. During the following planting season maize was planted in all plots.

2.5. Crop husbandry

Seeds were hand planted in 5cm deep furrows for all treatments at both localities. At planting, 40 kg N ha $^{-1}$ in the form of Lime stone ammonium nitrate (LAN - 28%N) and 50kg P ha^{-1} was applied as single superphosphate at Potchefstroom. At Taung, 50 kg N ha^{-1} in the form of Lime stone ammonium nitrate (LAN - 28%N) and 50kg P ha^{-1} was applied as single superphosphate. A hand hoe was used to incorporate the fertilizer at both locations. Weeds were controlled by hand hoeing three times during the growing period of all seasons at both localities. Maize stalk borer was controlled by application of Bulldock 0.05 GR. This granular product was applied manually to the funnels of plants using a container with a perforated lid. It was done once during the growing season at both localities.

2.6 Data collection

2.6.1. Yield determination

Maize and cowpea plants were hand harvested from middle rows at physiological maturity at Taung and Potchefstroom. Number of cobs were counted, measured, weighed and threshed. Grain yield, number of kernels per cob and 100 seeds weight were determined. Cowpea number of individual leaves at harvest, vines and seeds per pod were counted. Pod were weighed and threshed.

2.6.2. Stover yield

Stover yield was determined by harvesting the middle rows of maize crops at harvest in each experimental unit and the total Stover was weighed in the field using a hand-held suspension weighing scale.

2.6.3. Plant height

Plant height of maize crops was measured periodically throughout the growing season. Five plants per plot from middle rows were measured from each experimental unit using a meter stick.

2.6.4. Dry matter yield

Above ground plant samples were taken for cowpea at all locations during the planting season. Cowpea plants were cut at ground level to determine aboveground dry matter by oven drying at 65^{o}C for 72 hours. Dry matter samples of the crops were taken from 8m^2 area from each plot at harvest at all locations.

2.6.5. Plant and soil analyses

Maize plants were randomly selected from each plot for nutrient analysis at two different physiological stages (flowering and maturity). All plant samples were oven dried at 65 ^{0}C for 72 hours and finely ground to be analyzed for N, P and K. Nitrogen uptake by plants was measured through tissue analysis of ground dry matter samples using the semi – micro Kjeldal procedure and the results were read using an atomic adsorption spectrophotometer. Phosphorus and potassium were also measured by using dry ash methods and the results were read with an auto- analyzer. Soil sampling was carried out at two different stages, before planting and at the end of the first season.

The soil samples were dried and sieved to pass through a 2mm sieve and analyzed for mineral N (NH_4 and NO_3) was determined using 1: 5 extracted using 0.1N; Phosphorus (P) using Bray 1 method, Molybdenum reagent was used to extract phosphorus from the soil at 1:5 soil water ratios. A spectrophotometer with light band was used to determine the concentration of phosphorus in the soil extract and potassium was determined by means of an atomic absorption spectrophotometer (Jackson, 1967). pH (KCL) was measured using a pH meter, Organic carbon was measured using Walkey Black method and Basic cations (Ca, K, Mg, and Na).

2.6.6 Enzyme activity

Enzyme activity was assayed as described by Tabatabai (1994). Dehydrogenase activity was determined by the reduction of triphenyltetrazoliun chlorite (TTC) 1% to rtiphenylformzan (TPF) after incubation for 24 hours at 30 ^{o}C.

2.2.7. Statistical analysis

Data were analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS) (SAS Inst., 1996). The differences between treatment means was separated using Least Significant Difference (LSD) test.

CHAPTER 3: EFFECT OF CULTIVARS AND PLANTING DENSITY ON YIELD AND YIELD COMPONENTS OF COWPEA AND SOIL N CONTENT

3.1. Introduction

Cowpea is an important food legume in many African countries and in Brazil (Oladiran, 1994). Legumes are important in farming systems of the sub-humid and humid-tropical regions of developing countries. Cowpea provide a relatively inexpensive dietary source of protein and serve as organic nitrogen fertilizer for cereal crops grown either in a relay or as rotational crops, particularly when the straw is not harvested (Awonaike *et al.,* 1990).

Studies with several annual crop species have shown that yield potential can be increased by growing appropriate cultivars at extremely high plant densities (Cooper, 1977; Grafton *et al.,* 1988). For cowpea, Nangju (1979) concluded that cultivars with different plant morphologies would require optimum densities to express their full seed yield potential. To produce high seed yield at high plant density, a cultivar should efficiently use photosynthetically active radiation and effectively partition photosynthate to seed (Kwapata & Hall, 1990a). Plant density may influence light distribution in plant canopies (Kasperbauer & Karlen, 1986), but according to (Spaeth *et al.,* 1984) partitioning of photosynthate in soybean was barely influenced by density. Therefore, cowpea cultivars with high partitioning at low plant density consequently produce very high seed yields (Kwapata & Hall, 1990b). When evaluating response to plant density in indeterminate crops such as cowpea, it is important to study the dynamics of pod production. Plants at high density may have greater initial production of pods but less late season production, and total seasonal pod production may not be different from that of plants at low density (Kwapata & Hall, 1990a).

Soil is one of the most basic resources on which agriculture is based. Areas in Africa have soils that are poor in organic matter, N and P, where nutrient cycling is critical to maintain the productivity of the land and maximize the benefits from nutrient inputs (Powell *et al.,* 1996). Agricultural farming depends on intensive inputs of fertilizers, which may result in contamination of the environment and cause soil erosion. An alternative farming system can be used to lower the inputs of chemicals and use natural biological processes. To effectively reverse soil degradation, improve crop diversification and achieve greater sustainability of land use, much greater use of legumes in cereal production systems has been advocated (Biederbeck, 1990).

N_2 fixation capability of legumes offers an alternative for farmers to grow their own N in the form of green manure forages or pulse crops in related cereal based cropping systems (Biederbeck *et al.,* 2005). Legume based cropping systems will not only reduce nitrogen losses, but they may also increase the proportion of crop residue carbon that is sequestered in stable soil organic matter (Drinkwater *et al.,* 1998). Furthermore, the incorporation of legumes into the soil may provide organic N for the subsequent cereal. For agriculture to be sustainable there is a need to provide for the present nutrient requirements without compromising the future, sustain yields and maintain soil quality.

According to Vanlauwe *et al.,* (2000) N is the most limiting nutrient for production in most agricultural systems. Since nutrients can be lost through leaching and erosion, they should be returned into the soil. Therefore it is necessary to manage N in the soil to sustain crop yield and minimize environmental impact. The most important effect of the legumes however, is to increase plant-available nitrate N in the soil. Higher concentrations of soil nitrate result from conservative use of nitrate by the preceding legume crop, as well as the release of mineral N from legume residues (Herridge *et al.,* 1995 & Dalal *et al.,* 1998).

Soil enzymes play an essential role in mediating biochemical transformations involving the decomposition of organic residues and nutrient cycling in soil (Mc Latchey & Reddy, 1998) and they are derived primarily from microorganisms, plant roots and soil animals. Thus, soil enzymes can be used as a sensitive index to monitor changes in soil microbial activity and soil fertility (Parthasarathi & Ranganathan, 2000) since they are related to the mineralization of important nutrient elements such as N and P.

Soil microbes play a significant role in transforming organic matter into ionic forms that can be used by plants. Various microbes tend to decompose organic matter (Bridges & Davidson, 1982). The most important groups of these microbes are bacteria, fungi and actinomycetes (Thompson & Troeh, 1978). Soil micro-organisms exert a major influence on ecosystem functions by regulating litter decomposition and nutrient dynamics, acting both as a source and sink of labile nutrients. In management systems where synthetic chemical use is reduced, there is an increased reliance on biological soil processes and on high microbial diversity, since soil microorganisms mediate most of the processes that are essential to agricultural productivity (Paul & Clark, 1996). Thus alternative systems typically represent an attempt to optimize the soil internal cycling efficiency of nutrients, and to maximize the efficient use of external resources (Kirchner *et al.,* 1993).

Systems that increase belowground inputs of carbon and N through inclusion of legumes in rotation often increase microbial populations, diversity, biomass and activity above that observed for conventional management using commercial fertilizers (Bolton *et al.,* 1985, Doran *et al.,* 1987 & Biederbeck *et al.,* 1999). However, there are a number of other factors that determine organic matter decomposition, namely: temperature, soil pH, land-use system, and moisture availability (Paul & Clark, 1989).

This chapter presents the results of cowpea cultivar and planting density effects on yield and yield components during the 2005/06 planting season. Soil nutrient content and enzyme activities at the end of two planting seasons (2005/06 and 2006/07 planting seasons) and the enzyme activities in the soil after planting cowpea are also presented. Dehydrogenase in soil systems is involved in many different metabolic processes and form an integral part of the overall microorganism function in soil. Therefore the result of the assay of dehydrogenase activity would represent general activity of the active population.

3.2 Results and discussion

3.2.1 Effect of cowpea cultivars and planting density on grain yield and yield components

3.2.1.1 Cowpea grain yield

All treatment effects were significant for cowpea grain yield at both locations (Table 1 and 2 Appendix). The long duration cultivar, TVU 1124 had the highest mean grain yield at both Potchefstroom and Taung (3097.9 and 2018.0 kg ha^{-1}) when compared to the medium and short duration (CH 84, Bechuana white and PAN 311) cultivars (Table 3.1). This shows that TVU 1124 is a high yielding cultivar that can be recommended, especially to the resource poor farmers, for human consumption.

At both locations the mean cowpea grain yield increased as planting density increased. Similar response was also observed by Kwapata & Hall (1990) for vegetable cultivars, where seed yield significantly increased with increasing plant density. However Oladiran (1994) did not find similar results but found that seed yield declined significantly with increase in plant population and suggest that the reduction in seed yield was adequately compensated for increase in plant population. At Taung Bechuana White and TVU 1124 grain yield did not increase as density increased. TVU 1124 had the highest yield (3416.7 kg ha^{-1}) at 40 000 plants ha^{-1}. The results show that Taung gave lower yields than Potchefstroom. This decrease in cowpea grain yield at Taung, may be due climatic conditions that differed for the two locations, as Taung experienced floods during that planting season. Cowpea is a drought tolerant crop which does not tolerate waterlogged conditions well. Cowpea pods were furthermore attacked by white flies at flowering stage, which could have lowered the yields.

Table 3.1 Effect of cowpea cultivars and planting density on grain yield (kg ha^{-1}) at both locations during 2005/06 growing season.

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		Grain yield (kg ha^{-1})			
CH 84	1083.3a	1541.7abc	2083.3cd	2750.0e	1864.6b
PAN 311	1166.7ab	1745.8bc	2291.7de	2429.2de	1908.3b
TVU 1124	1583.3abc	2500.0e	2800.0e	5508.3f	3097.9a
Bechuana White	1125.0a	1791.7c	1791.7c	2875.0e	1895.8b
Mean	1032.8d	1392.7c	1881.3b	2658.9a	1966.54
LSD cultivar 291.5					
LSD density 291.5					
LSD interaction 583.1					
Taung					
CH 84	250.0a	875.0b	1041.7abc	1333.3a	875.0c

Pan 311	625.0ab	958.3abc	1708.3cd	1958.3de	1312.5b
TVU 1124	1095.8bc	895.8abc	2666.7ef	3416.7f	2018.0a
Bechuana White	1333.3cd	833.3ab	666.7ab	1000.0abc	958.3bc
Means	826.0b	890.6b	1520.8a	1927.1a	1291.04

LSD cultivar 211.2

LSD density 211.2

LSD interaction 422.4

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

3.2.1.2 Dry matter yield (DMY)

At Potchefstroom significant differences were observed in DMY as influenced by cowpea planting densities, but cowpea cultivars were not affected (Table 1 Appendix). Medium and long duration cowpea cultivars had the highest dry matter yield compared to the short duration cultivar PAN 311 at both locations (although not significant). Ayisi & Mpanyane (2000) also found that the short duration cowpea cultivars had less dry matter yield than the medium and long duration cultivars. Planting density means for dry matter yield increased as density increased. This increase in DMY resulted in an increased amount of plant residues that could be incorporated into the soil.

At Taung no significant differences were observed as influenced by cowpea cultivars and planting densities (Table 2 Appendix). Bechuana white had the highest dry matter yield (1750.4 kg ha^{-1}) compared to other cultivars. The highest dry matter yield (1995.3 kg ha^{-1}) was observed at 15 000 plants ha^{-1}. Generally, Bechuana white had higher dry matter yield than other cowpea cultivars at both locations. This correspond to the increased soil NO_3^- content measured (Table

3.8) which showed that soil NO_3^- content in maize following Bechuana White was higher (7.18 and 1.14 mg kg^{-1}) compared to other cowpea cultivars at both locations. Dry matter yield was higher at Potchefstroom compared to Taung. The total dry matter yield at Taung was ranging from 1269.5 to 1750.4 kg ha^{-1} among the cowpea cultivars and at Potchefstroom DMY ranged from 1407 to 1907.6 kg ha^{-1}. This shows that Potchefstroom had more dry plant residues incorporated than Taung.

Table 3.2. Effect of cowpea cultivars and planting density on dry matter yield (kg ha^{-1}) at both locations during 2005/06 growing season.

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		Dry matter yield (kg ha^{-1})			
CH 84	605.8a	1449.0abc	1945.4abc	2687.5c	1470.6a
PAN 311	879.5ab	1177.9abc	1328.7abc	2008.3abc	1405.7a
TVU 1124	1817.7abc	1818.9abc	2532.7c	2767.2c	1817.6a
Bechuana White	2529.8bc	2367.2abc	1151.7abc	2210.7abc	1907.6a
Means	1458.2b	1703.3ab	1739.6ab	2418.0a	1790.1
LSD cultivar 930.3					
LSD density 930.3					
LSD interaction 1860					
Taung					
CH 84	515.3a	1190.2ab	1928.1c	2217.6c	1462.8a
Pan 311	1951.0c	1554.2abc	1126.6ab	1446.0abc	1269.5a
TVU 1124	1595.1bc	1377.6abc	1139.0ab	1492.6abc	1401.1a
Bechuana White	2076.7c	1859.3c	2078.7c	1987.0c	1750.4a
Mean	1534.5a	1995.3a	1568.1a	1585a	1735.7
LSD cultivar 538.3					
LSD density 538.3					
LSD interaction 1076.6					

Means within the column and row followed by different letters are significantly different at P≤0.05.

3.2.1.3 Number of leaves

Number of leaves was significantly affected by cultivars and planting density (Tables 1 and 2 of Appendix) at both locations. The long duration cultivar TVU 1124 had a higher mean leave number (128.5 and 144.3) compared to medium and short duration cultivars (CH 84, Bechuana White and PAN 311) at both Potchefstroom and Taung. This shows that number of leaves produced is to some extent determined by the growing duration of cowpeas. At both Potchefstroom and Taung the highest mean number of leaves (110.1 and 161.1) was observed at 15 000 plants ha^{-1} compared to other densities.

At Taung, vegetative production was highly pronounced than in Potchefstroom. This could be attributed to higher rainfall during the growing season (Fig.1). Number of leaves increased with increasing density and at 20 000 plants ha^{-1} leaves started to decrease with increasing density. This shows that competition for light and nutrients between plants increased with increasing density.

Table 3.3 Effect of cowpea cultivars and planting density on the number of leaves per plant at both locations during 2005/06 growing season

Cowpea cultivars	Planting density 10 000	15 000	20 000	40 000	**Mean**
Potchefstroom		Number of leaves/plant			
CH 84	80.0cde	76.7bcde	54.3a	71.3bc	69.8d
Pan 311	67.7b	86.3e	73.0bcd	102.6f	82.3c
TVU 1124	123.0g	121.3g	131.7gh	138.0h	128.5a
Bechuana White	82.7de	159.0i	81.0cde	126.0g	112.2b
Mean	88.3b	110.1a	85.0b	109.3b	98.2

LSD cultivar 5.47
LSD density 5.47
LSD interaction 10.93

Taung

Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
CH 84	109.3a	135.3abc	132.0abc	116.3ab	123.3ab
Pan 311	127.7ab	115.0ab	125.3ab	84.7a	113.2b
TVU 1124	172.3bcd	192.0cd	118.3ab	94.3a	144.3a
Bechuana White	138.0abc	202.0d	113.7ab	118.0ab	142.9ab
Mean	136.8ab	161.1a	122.3bc	103.3c	130.9

LSD cultivar 30.936
LSD density 30.936
LSD interaction 61.87
Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

3.2.1.4 Number of vines

Number of vines were significantly affected by cowpea cultivars and planting densities at both locations (Table 1 and 2 Appendix). The long duration cowpea cultivar, TVU 1124 had higher (204.8 and 172.0) mean number of vines compared to other cultivar means at both locations. This can be attributed to the longer growth duration and growing pattern of TVU 1124, a spreading cultivar. The mean number of vines corresponds to higher number of leaves produced by TVU 1124 at both localities. It can be concluded that the more the branches, more leaves are produced.

Table 3.4 Effect of cowpea cultivars and planting density on the number of vines, at both locations during 2005/06 growing season

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40000	Mean
Potchefstroom		Number of vines/ plant			
CH 84	107.0abcd	120.0bcde	148.0defg	158.0efghi	133.3c
Pan 311	110.0abcde	85.7abc	65.7a	74.0ab	83.8d
TVU 1124	249.3k	152.0defgh	213.3jk	204.3ijk	204.8a
Bechuana White	177.3ghij	171.3fghij	184.0hij	124.3cdef	164.3b
Mean	160.9a	132.3b	152.8ab	140.2ab	146.6

LSD cultivar 24.154
LSD density 24.154
LSD interaction 48.31

Taung

CH 84	125.1c	105.6ab	119.7bc	222.2f	143.1b
Pan 311	127.2c	112.1ab	71.0a	169.0de	119.8b
TVU 1124	209.2ef	185.9def	133.3c	159.5cd	172.0a
Bechuana White	138.8cd	130.2c	100.8ab	111.6ab	120.4b
Mean	150.1ab	133.4b	106.2c	165.6a	138.8

LSD cultivar 23.9
LSD density 23.9
LSD interaction 47.85
Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

Short duration cowpea cultivar PAN 311 had the lowest (83.8 and 119.8) mean number of vines at both localities. This can be influenced by the growing pattern of cowpea as PAN 311 is an upright plant and other cultivars were spreading cultivars. At Potchefstroom the highest mean vine number (160.9) was recorded at 10 000 plants ha^{-1}. This can probably be attributed to less competition for light, water and space. It was also found by Oladiran (1994) that (significantly fewer) branches, peduncles and fruits per plant were produced on densely populated plots. At Taung the highest mean number of vines was recorded at 40 000 plants ha^{-1}.

3.2.1.5 Number of seeds per pod

The number of seeds per pod of cowpea was significantly affected by cowpea cultivars but not planting density at Potchefstroom (Table 1 Appendix). TVU 1124 had more seeds per pod (18.5) compared to other cultivars (Table 3.5). Even though planting density was not significant, the highest mean seed number (18.4) was recorded at 15 000 plants ha^{-1}. At Taung significant differences were observed as affected by planting density (Table 2 Appendix) but not cowpea cultivars. The mean seed number per pod was lower (14.6) at 20 000 plants ha^{-1}, compared to other planting densities.

Table 3.5 Effect of cowpea cultivars and planting density on number of seed per pod at Potchefstroom during 2005/06 growing season

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom	Number of seeds per pod				
CH 84	17.0ab	18.0abc	18.0abc	17.3abc	17.6a
Pan 311	17.7abc	18.3bc	18.0abc	18.0abc	18.0ab
TVU 112	19.3d	19.3d	16.3a	19.0cd	18.5b
Bechuana White	18.0abc	18.0abc	18.3bc	17.3abc	17.9ab
Mean	18.0a	18.4a	17.7a	17.9a	18
LSD cultivar 0.9					
LSD density 0.9					
LSD interaction 1.8					
Taung					
CH 84	19.0c	16.7abc	14.7ab	17.0abc	16.8a
Pan 311	16.3abc	17.3bc	14.7ab	15.3ab	15.9a
TVU 1124	16.0abc	16.7abc	15.0ab	17.3bc	16.3a
Bechuana White	15.7ab	14.3ab	14.0a	16.7abc	15.2a
Mean	16.8a	16.3a	14.6b	16.6a	16.1

LSD cultivar 1.64

LSD density 1.64

LSD interaction 3.29

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

3.2.2 Effect of cowpea on soil properties

3.2.2.1 Nitrate-N content (NO_3^-)

Residual Nitrate-N content (NO_3^-) sampled at the end of the 2005/06 planting season (after cowpeas) was significantly affected by cowpea cultivars and planting densities (Tables 3 and 4 of Appendix) at both locations. The long and medium duration cultivars TVU 1124, Bechuana White and CH 84 resulted in the highest mean soil NO_3^- content (8.16, 7.19 and 6.06 mg kg^{-1} at Potchefstroom and 5.33, 6.36 and 4.21 mg kg^{-1} at Taung) when compared to the short duration cultivar PAN 311 had the lowest (2.01 and 3.36 mg kg^{-1}) NO_3^- content (Table 3.6). This correspond to the results presented in chapter 4 (Table 4.1) that mean maize grain yield of maize following PAN 311 had the lowest yield at both Potchefstroom and Taung. This present study results indicates that the lower NO_3^- content could be influenced by to the fact that PAN 311 is a short duration cultivar and may be fixing less N (NO_3) content for the following maize crop.

The mean soil NO_3^- content increased as planting density increased at both locations. The mean soil NO_3^- content was higher at 40 000 plants ha^{-1} (7.93 and 6.42 mg kg^{-1}) when compared to the other densities at both Potchefstroom and Taung. This indicates that the higher cowpea plants result in improved soil NO_3^- content. From the results it can be concluded that residual soil NO_3^- content were affected by different growth duration of cowpea cultivars.

Table 3.6 Measured NO_3^- content (mg kg^{-1}) in the soil after 2005/06 planting season for different cowpea cultivars and planting densities at both locations

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		NO_3^- (mg kg^{-1})			
CH 84	3.32defg	2.97efg	5.65bcdef	12.32a	6.06a
PAN 311	1.18fg	1.13g	3.47defg	2.27efg	2.01b
TVU 1124	4.35cdefg	10.02ab	10.02ab	8.27abd	8.16a
Bechuana White	5.68bcde	6.47bcde	7.72bcd	8.88ab	7.19a
Mean	3.63c	5.15bc	6.71ab	7.93a	5.86

LSD cultivar 2.242
LSD density 2.242
LSD interaction 4.484

Taung

CH 84	2.27ab	4.68abc	4.17abc	5.72abc	4.21ab
PAN 311	2.47ab	1.80a	3.35abc	5.88aabc	3.36a
TVU 1124	3.18abc	3.80abc	5.60abc	8.72c	5.33ab
Bechuana White	6.23abc	7.98bc	5.35abc	4.44abc	6.36b
Mean	3.54a	4.04ab	5.28ab	6.42b	4.82

LSD cultivar 2.630
LSD density 2.630
LSD interaction 5.261

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

At the end of the 2006/07 planting season no significant differences was observed as influenced by preceding cowpea cultivars and planting densities at both locations (Table 5 Appendix).

Table 3.7 shows the measured mean soil NO_3^- content when maize followed cowpea, compared with the mean maize mono-cropping (after 2006/07 planting season). Significant differences were observed in cropping system at both locations. At Potchefstroom maize mono-cropping resulted in the lowest mean soil NO_3^- content (5.92 mg/kg), compared to when maize followed different cowpea cultivars. This corresponds with maize yield trends in chapter 4 (Table

4.2): maize following cowpeas had highest yield, compared to maize mono-cropping. This increase in soil NO_3^- content might be the results of cowpea crop residues that were incorporated into the soil. Shafi *et al.,* (2007) also observed that incorporating crop residues into the soil resulted in an increased soil mineral N content compared to when the residues were removed.

The increase in soil N content was beneficial to the subsequent maize. According to Yamoah *et al.* (1998), high fertilizer N rates were unnecessary in legume-cereal rotations, because cereals normally do not respond well to high amounts of chemical N fertilizer when grown after legumes. At Taung soil NO_3^- content at which maize followed PAN 311 and after maize mono-cropping had the lowest soil NO_3^- content (0.74 mg kg^{-1}) while at which maize followed Bechuana white had the highest (1.14 mg kg^{-1}) soil NO_3^- content.

Table 3.7 Effect of cropping system on soil NO_3^- (mg kg^{-1}) content at both locations at the end of 2006/07 growing season.

	NO_3^- content (mg kg^{-1})	
Cropping system	Potchefstroom	Taung
CH 84 –Maize	7.15a	0.83ac
PAN 311-Maize	7.17a	0.74c
TVU 1124 –Maize	7.18a	0.97a
Bechuana White –Maize	7.18a	1.14b

Maize –Maize	5.92b	0.74c
LSD	1.09	0.21

Means within the column followed by different letters are significantly different at $P \leq 0.05$.

The results showed that Taung had lower residual soil NO_3^- content compared to Potchefstroom. These resulted in lower grain yield and N content in maize plants. The low soil NO_3^- content at Taung could be as a result of higher rainfall during November of the 2006/07 planting season (Fig. 2.1), since nutrients can be easily lost through leaching from the sandy Taung soils.

3.2.2.2 Ammonium N content (NH_4^+)

At Potchefstroom after the 2005/06 planting season no significant differences were observed in soil NH_4^+ content as affected by cowpea cultivars (Table 7 Appendix), but planting densities affected soil NH_4^+ content. Bechuana White resulted in the highest mean (3.05 mg kg^{-1}) soil NH_4^+ content when compared with other cowpea cultivar means. Cowpea planted at 20 000 plants ha^{-1} produced the highest mean levels of soil NH_4^+ content (3.60 mg kg^{-1}) compared to other planting densities (Table 3.8).

At Taung after the 2005/06 planting season no significant differences were observed in soil NH_4^+ content as affected by both planting density and cowpea cultivars (Table 8 Appendix), although Bechuana White resulted in the highest mean (0.70 mg/kg) soil NH_4^+ content. The highest mean soil NH_4^+ level (0.76 mg/kg) was observed at 15 000 plants ha^{-1}.

After the 2006/07 planting season, no significant differences in soil NH_4^+ level were observed at both locations as affected by cowpea cultivars and planting densities (Table 5 Appendix). The mean of soil NH_4^+ content after maize mono-cropping and maize following cowpea cultivars were also not significant.

Table 3.8 Measured NH_4 content (mg kg^{-1}) in the soil after 2005/06 planting season for different cowpea cultivars and planting densities at both locations

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		NH_4^+ content (mg kg^{-1})			
CH 84	2.22abd	2.27abc	3.97a	2.22abc	2.67a
PAN 311	1.98abc	1.80bc	3.72ab	1.97abc	2.37a
TVU 1124	3.17abc	2.88abc	3.60abc	1.63c	2.82a
Bechuana White	2.50abc	3.80ab	3.13abc	2.75abc	3.05a
Mean	2.47b	2.69ab	3.60a	2.14b	2.73

LSD cultivar 1.012
LSD density 1.012
LSD interaction 2.024

Taung					
CH 84	0.55a	0.80a	0.55a	0.68a	0.64a
PAN 311	0.55a	0.80a	0.58a	0.67a	0.65a

TVU 1124	0.68a	0.60a	0.68a	0.63a	0.65a
Bechuana White	0.55a	0.85a	0.77a	0.63a	0.70a
Mean	0.58b	0.76a	0.65ab	0.65ab	0.66

LSD cultivar 0.169
LSD density 0.169
LSD interaction 0.338

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

3.2.2.3 Enzyme activities

At Potchefstroom after 2005/06 planting season no significant differences were observed in soil enzyme activities as affected by planting densities (Table 3 Appendix) but cowpea cultivars resulted in significant differences. CH 84 resulted in the highest mean (178.0 μg INF g^{-1}) enzyme activity when compared with other cowpea cultivar means. The higher enzyme activities in soil can be as a result of active microbial biomass producing more enzymes that can stabilize soil organic matter. The changes occur due to the effect of microbial inoculants on the rhizospheric microbial population. According to Naseby *et al.* (1999), the increased soil enzyme activities found in the rhizosphere of mycorrizal plants indicate an increase in carbon and nutrient leakage from roots.

At Taung, after the 2005/06 planting season, no significant differences were observed in soil enzyme activities as affected by cowpea cultivars and planting densities (Table 8 Appendix) even though TVU 1124 resulted in the highest (23.48 μg INF g^{-1}) enzyme activity when compared to other cultivars (Table 3.9).

Table 3.9 Measured enzyme activity in the soil after 2005/06 planting season for different cultivars and planting densities at Taung

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean

Potchefstroom	Enzyme activity (μg INF g^{-1})				
CH 84	189.9ab	178.3abc	184.8ab	159.1bcdef	178.0a
PAN 311	139.2def	198.6a	135.8ef	161.1bcdef	158.7b
TVU 1124	141.7def	131.6f	144.9def	167.5abcd	146.4b
Bechuana White	166.1bcde	152.3cdef	141.1def	185.2ab	161.2b
Mean	159.21a	165.18a	151.63a	168.22a	161.1

LSD cultivar 5.39
LSD density 5.39
LSD interaction 10.79
Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

3.2.3 Summary and conclusions

Different cowpea cultivars responded differently to planting density. Cowpea grain yield was significantly affected by planting density and cultivars, with TVU 1124 giving higher grain yield compared to other cultivars at both Potchefstroom and Taung. Increasing planting density significantly increased cowpea yield at both locations. From the results it can be concluded that TVU 1124 can be planted for highest grain yield at both locations. DMY was not significantly affected by cowpea cultivars. At Potchefstroom DMY was increased with increasing plant density with 40 000 plants ha^{-1} giving the highest DMY. Number of leaves and vines were significantly affected by cowpea cultivars and planting density at both locations. Cowpea cultivars responded differently in number of seeds per pod, with TVU 1124 giving the highest seed number, compared to other cultivars. At both locations, lowest number of seed per pod was observed at 20 000 plants ha^{-1}.

Soil nutrients ($NO_3^-$and NH_4^+) responded to cowpea cultivars, planting densities and cropping system. Maize following medium and long duration cowpea cultivars had the higher soil NO_3^- content compared to short duration cultivars at both locations. Soil NO_3^- content was significantly affected by cropping system, with maize following any cowpea cultivar giving higher soil NO_3^- content, compared to maize mono-cropping at Potchefstroom. At Taung maize following PAN 311 and mono-cropping had the lowest soil NO_3^- content compared to other cropping systems. At Potchefstroom the highest NH_4^+ content was observed at 20 000 plants ha^{-1} while at Taung it was highest at 15 000 plants ha^{-1}. Enzyme activities were significantly affected by cowpea cultivars and CH 84 had the highest mean activity compared to other cultivars. NO_3^- content was strongly correlated with maize grain yield following cowpea cultivars at both locations. At Potchefstroom, higher NO_3^- contents generally gave higher grain yields.

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CHAPTER 4: EFFECT OF COWPEA CULTIVARS AND PLANTING DENSITY ON MAIZE YIELD AND YIELD COMPONENTS

4.1 Introduction

Maize is the most important summer cereal crop grown by both small-scale and commercial farmers in South Africa. Despite its importance in South Africa, maize productivity is still marginal on smallscale farmer's fields and there is a need to enhance or maintain maize yield (Luphadzi, 1998; Mpangane, 2001) under diverse environments. Low maize yield, mainly for small-scale farmers, is largely attributed to declining soil fertility and nutrient depletion, resulting from continuous cropping with little or no nutrient input. In South Africa, small-scale farmers plant maize in monocropping, rotation or intercropped with legumes to improve yields due to lack of funds for farm inputs. Crop production in smallholder systems is limited by multiple resources that operate simultaneously, and cause resource imbalance that eventually lead to poor yields (Kho, 2000).

In areas where small scale farmers practice continuous maize production, soil fertility and crop production declines due to inadequate inputs. Continuous cropping of maize at a grain yield above 1 t ha^{-1} $year^{-1}$ cannot be sustained without frequent and substantial additions of mineral nutrients. Legume-cereal rotations in Southern Africa have been recognized for restoring soil fertility and increasing crop productivity (MacColl, 1989). Annual legume crops, grown in rotation with cereals crops, can improve the cereal yields and contribute to the total N pool in the soil. Reported yield responses to previous legume crops are often in the range of 50-80% increases over yields in cereal-cereal sequences (Evance *et al.,* 1991; Oikeh *et al.,* 1998) without fertilizer input.

The rotation of maize, legumes and rye grass may also supply N to a subsequent maize crop. There is little need for additional N fertilizer if legume-cereal rotation is practiced (Schroder *et al.,* 2000). Groundnuts in rotation can double the grain yield of the following maize crop under favourable management when groundnut residues are incorporated into the soil (McDonagh *et al.,* 1993).

N and P are the most studied elements in the flows and balances of nutrients in agricultural systems (Smalling *et al.,* 1999). N requirements can be supplied through the inclusion of legumes in crop rotation and through the use of organic amendments in organic agriculture. Legumes must supply enough N for the succeeding crops. In many farming systems, legumes produce poor commercial returns unless they play a role as green manure (Rodrigues *et al.,* 2006). The rotation effects of legumes can be related to root-induced processes leading to nutrient release from mineralization of the legume residues.

4.2 Results and discussion

4.2.1 Maize grain yield

Maize grain yield was not significantly affected by cowpea cultivar and planting density but the interaction was significant during the 2006/07 season, at Potchefstroom respectively (Table 6 Appendix). Maize following medium and long duration cowpea cultivars had the highest mean grain yield when compared to means of maize following the short duration (PAN 311) cultivars at both locations (Table 4.1).

Table 4.1. The effects of cowpea cultivars and planting density on maize grain yield (kg ha^{-1}) at both locations during the 2006/07 growing season.

Potchefstroom		Planting density			
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
CH 84	4000abc	4667c	3417abc	3908abc	3998a
PAN 311	3500abc	4417bc	2417ab	3692abc	3506a

TVU 1124	4250abc	3583abc	4417bc	2258a	3627a
Bechuana White	4117abc	3417abc	3417abc	3167abc	3529a
Mean	3967a	4021a	3417a	3256a	3665
LSD density 1022.4					
LSD cultivar 1022.4					
LSD interaction 2044.8					
Taung					
CH 84	2833bcd	2417cd	2667bcd	4083a	3000a
PAN 311	2250cd	1750d	2458cd	3000abc	2021b
TVU 1124	2167cd	3208abc	3250abc	3792ab	3104a
Bechuana White	2583cd	2542cd	2916abcd	2792bcd	2708a
Mean	2333b	2427b	2822ab	3250a	2708
LSD density 598.7					
LSD cultivar 598.7					
LSD interaction 1197					

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

At Taung, maize grain yield was significantly affected by cowpea cultivars and planting densities (Table 7 Appendix). Maize following different cowpea cultivars responded differently regarding grain yield. Maize performance was probably influenced by the growing duration of cowpea cultivars as maize following PAN 311, the only shortest duration cultivar, had the lowest grain yield at both locations (although not significant at Potchefstroom). Planting density means also show that maize grain yield increased as density of the preceding cowpeas increased. This indicates that higher cowpea plant population probably improved soil nutrient levels more, due to more plant residues produced and it's incorporation into the soil. Grain yield of maize following CH 84, PAN 311 and TVU 1124 was highest (4083, 3000 and 3792 kg ha^{-1}) at 40 000 plants ha^{-1},while maize following Bechuana white was highest (2916 kg ha^{-1}) at 20 000 plants ha^{-1}.

In Table 4.2 the mean grain yields of maize following different cowpea cultivars were compared with mean grain yields of maize monocropping. Significant differences were observed in cropping system at both locations. At Potchefstroom the mean maize grain yield following cowpea increased by between 2454 and 2946 kg ha^{-1}, depending on the cowpea cultivar. At Taung the increase was between 1810 and 2549 kg ha^{-1} when compared to maize mono-cropping. Dakora *et al,* (1987), also found that maize grain yield increased by 89% when grown after groundnut as compared to non-fertilized fallow. This effect was equivalent to additions of 60 kg ha^{-1} inorganic N. McDonalgh *et al.* (1993), also found that maize yield increase up to 65% where groundnut residues were returned, approximately equivalent to the response from 75 kg N ha^{-1} as urea to the fallow treatment. The results of the present study confirm that maize grain yield increases when planted in sequence with legume crops.

Table 4.2 The effects of sequential cropping system on maize grain yield (kg ha^{-1}) at both locations during the 2006/07 growing season.

	Potchefstroom	Taung
Cropping System	Grain yield (kg ha^{-1})	
CH 84-Maize	3998a	3000a
PAN 311-Maize	3506a	2365b
TVU 1124 -Maize	3627a	3104a
Bechuana White -Maize	3626a	2708a
Maize- Maize	1902b	1281c
LSD	1052	555

Means within a column followed by different letters are significantly different at $P \leq 0.05$.

The differences in yields for the two locations can probably be attributed to different rainfall amounts at the two locations. Potchefstroom received more monthly rainfall than Taung (Fig. 2.1 and 2.2), which probably resulted in higher grain yields. In addition, Taung is a very warmer and drier area than Potchefstroom. These differences in maize yield can also be influenced by the soil type as Taung soil was sandy and nutrients can be lost through leaching.

There was no fertilizer applied during 2006/07 planting season when maize was following cowpea. Therefore, the increased maize grain yields without application of fertilizers can be influenced by the incorporation of cowpea plant materials into the soil as dry residues before the planting of maize, when compared with maize – maize plots. Nel *et al.* (1996) found that in a long-term maize-legume rotation trial in South Africa, fertilized maize grain yields were improved by 2 tha^{-1} in rotation with field pea (*Pisum arvense Poir*), compared with unfertilized continuous maize. The results of the present study suggest that sequential cropping with cowpeas contributed a considerable amount of N to the succeeding maize crop. The mean maize grain yield increase at 15 000 plants ha^{-1} corresponds to the mean cob length and means 100 seed mass as observed (Table 3.4 and 3.8) at Potchefstroom. This shows that when the cobs are longer and seed mass increased, the more grain yield can be produced.

4.2.2 Stover yield

No significant differences in maize stover yields were observed in response to different cowpea cultivars and planting densities at both locations (Table 6 and 7 Appendix). Table 4.3 shows the means of maize stover yield following different cowpea cultivars, compared with the means of maize following maize. At Potchefstroom there were no significant differences between cropping systems, but maize following PAN 311 had the lowest stover yield (4279 kg ha^{-1}) compared to other cropping systems.

At Taung stover yield was significantly influenced by cropping system. Maize followed by maize had lower stover yield (5138.7 kg ha^{-1}) when compared to maize following cowpeas (CH 84, PAN 311, TVU 1124 and Bechuana white). This effect can be attributed to decomposition of legume residues with higher N concentration than cereal residues. Shah *et al.* (2003) also found that the previous crop (chickpea) had significant impact (P<0.05) on the stover yield of succeeding maize.

Table 4.3 The effects of maize sequential cropping system on stover yield (kg ha^{-1}) at both locations during 2006/07 growing season.

	Potchefstroom	Taung
CH 84-Maize	5081a	6814a
PAN 311-Maize	4279a	6146ab
TVU 1124 -Maize	5139a	6012ab
Bechuana White -maize	5674a	6318a
Maize- Maize	5378a	5138b
LSD	1423.9	1015.9

Means within a column followed by different letters are significantly different at $P \leq 0.05$.

4.2.3 Cob length

At Potchefstroom during the 2006/07 season, significant differences in maize cob lengths were observed in response to preceding cowpea planting densities (Table 4 Appendix). The mean maize cob length following different cowpea cultivars were not significantly different, although maize following TVU 1124 had the longest cobs (Table 4.4). Maize following CH 84, PAN 311 and Bechuana white had the longest cobs (15, 17 and 15 cm) at 15 000 plants ha^{-1}. This corresponds to the maize gain yield for some cultivars: at the same location maize following CH 84 and PAN 311 had highest grain yields at 15 000 plants ha^{-1} (Table 4.1). This means that the longer the cobs, the higher the grain yield is produced.

Table 4.4 The effects of cowpea cultivars and planting density on maize cob length (cm) at both locations during 2006/07 growing season.

		Planting density			
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		Cob length (cm)			
CH 84	14.67abc	15.00ab	14.00bc	12.67bc	14.58a
PAN 311	15.33ab	17.00a	14.67abc	12.67bc	14.91a
TVU 1124	17.00a	14.33abc	15.00ab	14.00bc	15.08a
Bechuana White	13.67bc	15.00ab	12.33c	13.33bc	13.58a
Mean	15.17a	15.33a	14.00ab	13.17b	14.53
LSD cultivar 1.50					
LSD density 1.50					
LSD interaction 3.0					
Taung					
CH 84	11.67abcd	12.33abcd	10.67cd	13.67ab	12.1ab
PAN 311	11.33abcd	10.67cd	11.67abcd	12.00abcd	11.4b
TVU 1124	13.33abc	12.33abcd	13.67ab	14.00a	13.3a
Bechuana White	12.33abcd	11.06bcd	11.67abcd	10.00d	11.8b
Mean	13.20a	12.77a	13.70a	12.83a	12.6
LSD cultivar1.37					
LSD density 1.37					
LSD interaction 13.7					

Means within the column and row followed by different letters are significantly different at P≤0.05.

At Taung no significant differences were observed in response to preceding cowpea planting densities (Table 7 Appendix) but preceding cowpea cultivar had a significant effect on maize cob length. Maize following TVU 1124 had the longest mean cob length (13.3 cm), compared to other cultivars. Maize following the short duration cultivar PAN311 had the shortest cobs (11.4 cm). Cob length of maize following CH 84, PAN 311 and TVU 1124 were longer (13.67, 12.00 and 14.00 cm) at 40 000 plants ha^{-1}. This also corresponds to maize grain yield results, as grain yield was highest at the same preceding cowpea planting density (40 000 plants ha^{-1}) for these cultivars (Table 4.1).

Table 4.5 The effects of maize sequential cropping system on maize cob length (cm) at both locations during 2006/07 growing season.

	Potchefstroom	Taung
Cropping system	Cob length (cm)	
CH 84-Maize	14.58a	12.1ab
PAN 311-Maize	14.91a	11.4bc
TVU 1124 -Maize	15.08a	13.3a
Bechuana White -	13.58a	11.8b
Maize- Maize	14.71a	10.3c
LSD	1.4	1.1

Means within a column followed by different letters are significantly different at $P \leq 0.05$.

Table 4.5 shows how cropping system influenced maize cob length during the 2006/07 planting season. No significant differences were observed between cropping systems at Potchefstroom. At Taung there were significant differences between cropping systems. Maize mono-cropping had the shortest cobs (10.3 cm), compared to maize following any of the cowpea cultivars. Sequential cropping probably resulted in improved soil N, which resulted in better plant growth and longer maize cobs.

4.2.4 Kernel number of per cob (KNC)

The data for Potchefstroom was not shown, because no significant difference in kernel number per cob (KNC) was observed as influenced by preceding cowpea cultivars and planting densities (Table 4 Appendix). The highest maize KNC mean for planting density was (429.9) at 15 000 plants ha^{-1} compared to other densities. The mean planting density correspond to the mean maize grain yield and cob length at 15 000 plants ha^{-1}. At Taung no significant difference was observed in KNC as influenced by preceding cowpea planting density, but cowpea cultivars gave significant differences (Table 3 Appendix). Maize following the long duration cultivar, TVU 1124 had a higher mean KNC than CH 84, PAN 311 and Bechuana White cultivars (Table 4.6) and the short duration cultivar, PAN 311 had the lowest KNC. This also corresponds to the mean maize grain yield and cob length at the same location.

In Table 4.7 maize mono-cropping was compared with maize following cowpea cultivars. At Potchefstroom KNC was not significantly affected by cropping systems, but maize following TVU 1124 had the highest (397.2) mean kernel number per cob and maize following Bechuana white had the lowest KNC (371.9) when compared to other cropping systems. At Taung there were significant differences between cropping systems. Maize following maize had the lowest KNC (242.5) when compared to maize following cowpeas. These results correspond with the increased maize grain yield and cob length as a result of cowpea rotation cropping system at Taung. The improved KNC might have been as a result of improved plant growth and nutrient availability in the soil.

Table 4.6 The effects of cowpea cultivars and planting density on number of kernels per cob (KNC) at both locations during the 2006/07 growing season at Taung.

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Taung		kernel number per cob			
CH 84	247.0cd	306.7abcd	244.3d	386.0a	296.0a
PAN 311	259.3cd	286.3bcd	290.7bcd	289.3bcd	281.4a
TVU 1124	352.3ab	316.7abcd	331.7abc	381.7a	345.6b
Bechuana White	322.3abcd	301.7abcd	300.7abcd	258.0cd	295.7a
Mean	312.4a	302.8a	289.4a	329.1a	302.8

LSD cultivar 42.8

LSD density 42.8

LSD interaction 85.5

Means within the column and row followed by different letters are significantly different at $P \leq 0.05$.

Table 4.7 The effect of sequential cropping system on maize number of kernels per cob (KNC) at both locations during the 2006/07 growing season.

	Potchefstroom	Taung
CH 84-Maize	396.5a	296.0b
PAN 311-Maize	382.8a	281.4bc
TVU 1124 -Maize	397.2a	345.6a
Bechuana White -Maize	371.9a	295.7b
Maize- Maize	399.9a	242.5c
LSD	56.9	43.1

Means within a column followed by different letters are significantly different at $P \leq 0.05$

4.2.5 Hundred (100) seed mass

Preceding cowpea cultivars significantly affected 100 seed mass at Potchefstroom (Table 4 Appendix) but planting density did not affect it. At Potchefstroom (Table 4.8) the mean 100 seed mass of maize following long and medium duration cowpea cultivars (Bechuana white, TVU 1124 and CH 84) were the highest (31.7, 31.2 and 30.3 g), compared to maize following the short duration cultivar, PAN 311 (26.8g). At Taung no significant differences were observed in 100 seed mass, as influenced by preceding cowpea cultivars and planting density.

Table 4.9 shows the differences in 100 seed mass between maize mono-cropping and maize following cowpea cropping systems. Hundred seed mass was significantly influenced by cropping system at both locations. At Potchefstroom maize following PAN 311 and maize mono-cropping had the lowest seed mass (26.8 and 27.9 g), compared to maize following other cultivars. At Taung the highest seed mass was recorded by maize following cowpeas (all cultivars) compared to maize mono-cropping (26.2 g). The improved kernel mass of maize in crop rotation might have been as a result of the improved plant growth and soil nutrient status at both locations.

Table 4.8 The effect of cowpea cultivars and planting density on maize hundred seed mass at both locations during the 2006/07 growing season at Potchefstroom.

		Planting density			
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		100 seed mass (g)			

CH84	29.6abc	33.0a	29.4abc	29.0abc	30.3ab
PAN 311	22.8c	28.4abc	30.4ab	25.5bc	26.8b
TVU 1124	32.8a	27.4abc	30.6ab	34.0a	31.2a
Bechuana White	30.8ab	34.0a	28.8abc	33.3a	31.7a
Mean	30.1a	31.2a	29.8a	28.8a	30.1

LSD cultivar 3.645

LSD density 3.645

LSD interaction 7.29

Means within the column and row followed by different letters are significantly different at P≤0.05.

Table 4.9 The effect of sequential cropping system on maize hundred seed mass (g) at both locations during the 2006/07 growing season.

	Potchefstroom	**Taung**
CH 84-Maize	30.3abc	29.6ab
PAN 311-Maize	26.8c	29.8ab
TVU 1124 -Maize	31.2ab	30.8a
Bechuana White -Maize	31.7a	27.8bc
Maize- Maize	27.9bc	26.2c
LSD	3.4	2.5

Means within a column followed by different letters are significantly different at P≤0.05

4.2.6 Plant height

Maize plant height at Potchefstroom was significantly affected by preceding cowpea cultivars and planting densities (Table 6 Appendix). Maize following Bechuana white had the tallest mean plant height (181.5cm), compared to other cultivars means at both locations (Table 4.10). Maize plant height at 10 000 plants ha^{-1} had the tallest plants (180.8 cm). At Taung, preceding cowpea cultivars significantly affected plant height (Table 7 Appendix). Maize following Bechuana white gave the tallest mean plant height (181.6cm) compared to maize following CH 84, PAN 311 and TVU 1124 (168.2, 168.3 and 164.0cm), respectively (Table 4.10). There was significant difference in the mean plant height as influenced by cowpea planting densities.

In Table 4.11 the mean plant heights of maize following cowpea cultivars were compared with the mean height of maize in mono-cropping. Cropping system significantly affected maize plant height at both locations. The mean plant height of maize in mono-cropping gave the shortest plants at both Potchefstroom and Taung (161.7cm and 154.7cm) when compared to the other cropping systems. These results correspond to Chabi-Olake *et al,* (2005), who found that plant height of maize after mucuna was 1.4 times taller than that of maize following maize. Sequential cropping of cowpea and maize increased plant height of maize compared to maize monocropping, especially at Taung where the soil was sandy and nutrients can be easily lost due to leaching if not supplemented. This increase in maize plant height following cowpea may be the result of increased nutrient levels in the soil as decomposed cowpea material improved the soil nutrient content. The improvements in plants height also correspond to the increased grain yields observed.

Table 4.10 The effect of cowpea cultivars and planting density on maize plant height (cm) at both locations during the 2006/07 growing season.

	Planting density				
Cowpea cultivars	10 000	15 000	20 000	40 000	Mean
Potchefstroom		Plant height (cm)			
CH84	164.0ab	160.7ab	166.7ab	181.7bc	168.2b
PAN 311	173.3abc	168.7ab	151.7a	179.3abc	168.3b
TVU 1124	163.7ab	167.3ab	171.0ab	154.0ab	164.0b
Bechuana White	201.3c	175.3abc	170.7ab	178.7abc	181.5a
Mean	180.8a	167.9ab	163.5b	169.7ab	170.5
LSD cultivar 14.67					

LSD density 14.67

LSD interaction 29.35

Taung					
CH84	155.7e	195.0a	175.3bcd	187.3ab	168.2ab
PAN 311	166.cde	171.0bcde	165.0de	175.0bcd	168.3ab
TVU 1124	176.3abcd	168.7bcde	164.3de	166.3cde	164.0b
Bechuana White	184.3abc	172.0bcde	185.0abc	183.0abcd	181.6a
Mean	170.7a	172.5a	169.1a	177.9a	171.5

LSD cultivar 9.62

LSD density 9.62

LSD interaction 19.23

Means within the column and row followed by different letters are significantly different at P≤0.05.

Table 4.11 The effects of sequential cropping system on plant height (cm) at both locations during 2006/07 growing season.

	Potchefstroom	Taung
CH 84-Maize	168.2ab	170.8a
PAN 311-Maize	168.3ab	169.3a
TVU 1124 -Maize	164.0b	168.9a
Bechuana White -Maize	181.5a	181.1a
Maize- Maize	161.7b	154.7b
LSD	13.1	11.8

Means within a column followed by different letters are significantly different at P≤0.05

4.2.7. Leaf N content of succeeding maize

At both locations, preceding cowpea cultivars and planting density did not significantly influence leaf N content of the following maize at all growing stages, as well as the grain N content. This might be an indication that cowpea cultivars responded similarly to N_2 fixation and planting density does not affect fixation. Table 4.12 shows the mean N content of maize leaves at flowering stage, maturity stage and in the grains, following different cowpea cultivars, compared with maize mono-cropping at Potchefstroom during the 2006/07 growing season. At flowering stage N content of maize monocropping was lower (1.37 %) when compared to other cropping systems. No significant differences were observed in N content at maturity stage and in grains. The N content in maize leaves was lower at maturity stage (0.72 %) than for other cropping system. These N levels in both leaf and grains are low especially at Taung which is below the critical value (2.9%).The lower N content may be due to climatic and soil conditions at Taung. The lower soil N content at Taung is the possible cause of the lower N content in maize plant (flowering stage) and grains. This resulted in shorter cobs and lower KNC.

Table 4.12 Effect of sequential cropping on N content (%) of maize leaves at flowering stage, maturity stage and grains at Potchefstroom during the 2006/07 growing season

	N concentration (%)		
Cropping system	Flowering	maturity	Grain
CH 84 –Maize	1.65ab	0.83a	1.51a
PAN 311-Maize	1.63ab	0.82a	1.50a
TVU 1124 –Maize	1.81a	0.85a	1.48a
Bechuana White –Maize	1.61ab	0.83a	1.45a
Maize –Maize	1.37b	0.72a	1.47a
LSD	0.303	0.135	0.187

Means within a column followed by different letters are significantly different at $P \leq 0.05$.

Table 4.13 shows the maize leaf and grain N content for different cropping systems of maize mono-cropping and maize following cowpea cultivars at Taung during flowering stage, maturity stage and in the grains. Maize following cowpea generally improved N content of the grains when compared to maize following maize (0.36 %), although not significant for cultivar TVU 1124. At flowering stage N content of maize in monocropping was lower (0.07%) when compared to maize following any of the cowpea cultivars. N content in maize leaves at maturity stage was not significantly affected by cropping system. The results of the present study show that N content for the subsequent crop was influenced by the amount of plant residues left in the soil, availability of N from the plant residues, especially at flowering stage and the extent to which soil N was depleted by the preceding crop.

Table 4.13 Effect of cropping system on N content (%) of maize leaves at flowering stage, maturity stage and in grains at Taung during the 2006/07 growing season

	N concentration (%)		
Cropping system	Flowering	Maturity	Grain
CH 84 –Maize	0.07d	0.06a	0.38ab
PAN 311-Maize	0.11bc	0.07a	0.39ab
TVU 1124 –Maize	0.12ab	0.07a	0.41a
Bechuana White –Maize	0.13a	0.09a	0.39ab
Maize –Maize	0.09cd	0.10a	0.36b
LSD	0.023	0.057	0.042

Means within a column followed by different letters are significantly different at $P \leq 0.05$.

4.2.8 Summary and conclusion

Maize yield and yield components responded to cowpea cultivars, planting density and cropping system. Maize grain yield was significantly affected by preceding cowpea growth duration with maize following PAN 311 giving the lowest yield compared to other cultivars at both locations. Maize grain yield was significantly affected by cropping system, with maize following cowpea cultivars generally giving higher yields compared to maize mono-cropping at both Potchefstroom and Taung. At Potchefstroom maize following PAN311 had lower 100 seeds mass and stover yield compared to other cropping systems. Plant height was also significantly affected by cropping system at both locations, with maize mono-cropping producing shorter plants than maize following cowpeas. N content at flowering stage was affected by cropping system, with maize mono-cropping giving the lowest N content when compared to other cropping systems.

At Taung cob length was increased by maize following cowpea. Maize following PAN 311 had lower stover yield. Maize following all cowpea cultivars had significantly more KNC than maize mono-cropping. Preceding cowpea cultivars significantly increased maize plant height with maize following Bechuana White giving the taller plants. N content at flowering stage and in grains were significantly affected by cropping system, with maize following CH 84 giving the lowest N content. Grains had the lowest N content in maize mono-cropping, when compared to other cropping systems. The maize grain yield components that were strongly correlated with maize yield were cob length and KNC at both locations. Maize performed better if planted in sequence with cowpea at both locations and most preferably at Potchefstroom because of higher grain yields.

Maize grain yield at Taung were lower than at Potchefstroom. This is probably the result of a combined effect of shorter cobs, lower KNC and lower 100 seed mass, when compared to Potchefstroom. Soil nutrient content at Potchefstroom were higher than at Taung. After cowpea planting, at the end of 2005/06 planting season soil NO_3^- and NH_4^+ content were lower at Taung than Potchefstroom. During the 2005/06 palnting season Taung was affected by floods and under those conditions soil N content that was fixed by cowpeas could be lost through leaching. Even the cowpea total dry matter yield at Taung was lower at Taung compared to Potchefstroom.

From the results it can be concluded that maize yield components like cob length and KNC were not significantly affected by cropping system at Potchefstroom. It might be as a result of the higher soil nutrient status and higher rainfall which improved maize growth. However, the practical implication of these results is that the sequential cropping of cowpea and maize can be integrated into farming systems, especially under small-scale farming.

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CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. Discussion

Short, medium and long duration cowpea cultivars showed an increasing grain yield as the planting density increased, with TVU 1124 performing better than other cowpea cultivars at both locations. DMY in general increased with increasing cowpea density at Potchefstroom. Cowpea had the highest yield at 40 000 plants ha^{-1} at both locations. The short duration cowpea cultivar (PAN 311) produced less DMY, which may be as a result of the shorter growth period. Increased yield by long duration cultivars was probably due to a higher number of seeds per pod. Since pod development occurs on branches, the more the numbers of vines produced, the more pods potentially produced. At both locations the highest number of vines was observed at 15 000 plants ha^{-1}. At Potchefstroom the highest number of seeds per pod was also observed at 15 000 plants ha^{-1}.

The observed improvement in soil NO_3^- content after cowpea shows that legume residues have contributed to the soil nutrient status. Soil NO_3^- content in the soil after maize following cowpea, was higher than maize monocropping at Potchefstroom. Sequential cropping of maize and cowpea cultivars showed no significant differences in soil NH_4^+ content. Different growth duration cowpea cultivars resulted in different soil NO_3^- contents: the short duration cultivar gave the lowest NO_3^- content in the soil at both locations. The highest soil NO_3^- content was observed at 40 000 plants ha^{-1} at both locations. Therefore, Soil NO_3^- content after cowpea cultivars showed an increase as plant density increased at both locations. Higher cowpea population resulted in higher residual N levels, which benefited the succeeding maize yield. Soil NO_3^- content corresponded strongly to cowpea grain yield. The full N benefits of the legumes are only realized if all residues are returned to the soil after the legume grain harvest (Jensen, 1995; Wani et al., 1995).

In maize plant height, maize following short, medium and long duration cowpea cultivars produced the tallest plants compared to maize monocropping at both locations. The observed improvements in maize growth reflect the improvements in soil nutrient status as a result of the addition of cowpea plant residues. However, this improvement was not only caused by the improvement in soil nutrient status, but also by the availability of plant-available N after planting cowpeas.

There are several factors contributing to the yield advantage. The major reason for the higher yields of maize after cowpea was an N carry over effect from the legume (Bowen *et al.,* 1988). This carry over may be due to N addition by legumes to the soil N pool, because of less removal of inorganic N from the soil, compared to cereals (Evans *et al.,* 1991). At Taung under drier conditions, maize stover yield increased by crop rotation and thus cob length and 100 seed mass improved. Under these conditions, more KNC was observed in maize following cowpea than maize mono-cropping. Maize cob length and KNC were strongly correlated with grain yield at both locations.

The study showed that the contribution of cowpea to subsequent maize significantly improved maize grain yield and growth. Maize grain yield response between the two localities was affected by different environmental conditions. Under wetter conditions, which occurred at Potchefstroom because of higher rainfall and better distribution, maize following all cowpea cultivars produced significantly higher grain yields. Under drier conditions cowpea planting density significantly increased maize yields. Crop rotation significantly increased maize grain yields compared to maize monocropping at both locations. Clark *et al.* (1997) and Chalk (1998) also found that cereals derive both yield and N benefits from rotations with grain legume compared with cereal monocultures. Medium and long duration cowpea cultivars result in higher yields, compared to short duration cultivar.

The results of this study suggest that cowpea cultivars could enhance soil fertility. Cowpea could be planted in rotation with cereals like maize to improve yield and crop growth. Under this system, cowpea can significantly improve maize grain yield compared to a maize mono-cropping system. A considerable amount of N was returned to the soil by incorporating cowpea dry residues into the soil after harvest. This incorporation of plant residues and cowpea nodulation, reduce the need for inorganic N on subsequent maize. Literature also confirms that carry over N in the soils becomes available for the next crop to use through N mineralization (Wienhold & Halvorson, 1999; Kolberg *et al.,* 1999; Honeycutt, 1999) which can increase productivity and profitability.

5.2 Conclusions

Generally, the study concluded that the rotational cropping of cowpeas at different planting densities had a significant positive effect on maize growth and yield. Cultivar TVU 1124 can be planted for its high grain and dry matter yield. Rotation with cowpea improved soil nutrient levels. Finally, the study concluded that sequential cropping increased maize grain yield and improved soil N content. This was indicated by significantly higher values of soil N content when compared to monocropping.

5.3. Recommendation

- Although it was found in this study that maize following cowpea in a rotational cropping system resulted in improved maize yield and soil nutrient status, probably not all nutrients were used by the maize plants. It is necessary to measure or estimate the amount of nutrients lost through leaching, volatilization and denitrification in order to do a complete nutrient balance calculation.

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CHAPTER 6. SUMMARY

Maize and cowpea are important crops that can be planted sequentially or in intercropping are used for both human consumption and animal feed. The main purpose of sequential cropping is for the use of nutrients loss. This cropping system is mainly practiced by small scale farmers as they cannot afford commercial fertilizers and sequential cropping can be used as alternative. The use of cowpea cultivars and planting densities at both locations significantly improved maize grain yields following these cultivars of cowpea. As there was no fertilizer addition after cowpea crops, the difference between cowpea-maize rotation plots and the N can be attributed by maize –maize rotation from the legumes and legume residues coming from the previous legume crop. Maize grain yield following legume are increased more than double the maize following maize. The higher grain yields of both crops at Potchefstroom could be attributed by the higher soil nutrient levels and rainfall distribution. The lower cowpea yields at Taung could also be due to pest accurance or flooding that occurred when cowpea plants were still in podding stage. Number of leaves and vines were increased by growth duration of cowpea cultivars at both locations.

The results show the soil N improvement as at Taung cowpea varieties and their planting densities improved soil N. Legumes can significantly reduce the need for external N inputs by contributing N_2 fixed from the atmosphere to the soil available N pool. The soil at Potchefstroom on which the study was carried out was more fertile than at Taung experimental farm where the study was carried out. Legume-maize rotation alleviated soil N deficiency. The retention of crop residues, inclusion of legumes in the cropping system significantly increased the soil N fertility and yields of maize. Returning crop residues and inclusion of legumes to the soil improves the N content and enhances crop productivity through the additional N.

APPENDIXES

Table 1. PR>F-values from the analysis of variance for cowpea number of leaves per plant, Number of vines and shoots dry matter (DM) yield (kg ha^{-1}), Pods weight (kg/ha) and 100 seeds weight (g) during 2005/06 growing season at Potchefstroom.

Treatment Effect	Number of leaves	Number of Vines	Shoots DM (kg ha^{-1})	Grain yield (kg ha^{-1})	seeds per pod
Cultivar	<0.0001	<0.0001	0.3676	<0.0001	0.2599
Density	<0.0001	0.0942	<0.0001	<0.0001	0.4351
CxD	<0.0001	0.0109	0.0002	<0.0001	0.1126
CV (%)	6.61	19.56	18.34	15.79	6.11

C X D is the cultivar and density interaction

CV is the coefficient of variation

Table 2 PR>F-values from the analysis of variance for cowpea number of leaves per Plant, Number of vines and shoots dry matter (DM) yield (kg ha^{-1}), pods weight (kg/ha) and 100 seeds weight (g) during 2005/06 growing season at Taung.

Treatment Effect	Number of Leaves	Number of Vines	Shoots DM (kg ha^{-1})	grain yield (kg ha^{-1})	Seeds per pod
Cultivar	0.1317	0.0004	0.0006	<0.0001	0.2334
Density	0.0061	0.0002	0.0184	<0.0001	0.0449
CXD	0.2345	0.0029	0.0051	0.0022	0.0615
CV (%)	28.05	20.45	24.45	38.83	12.1

C X D is the cultivar and density interaction

CV is the coefficient of variation

Table 3 PR>F-values from the analysis of variance for soil NO_3, NH_4, (mg/kg) (μg INF g^{-1}) and enzyme activity after 2005/06 growing season at Potchefstroom.

Treatments	NO_3 ((mg/kg)	NH_4 (mg/kg)	Enzyme activity (μg INF g^{-1})
Cultivar	<0.001	0.582	0.003
Density	0.003	0.037	0.161
C x D	0.063	0.706	0.002
CV (%)	45.9	44.5	11.6

C X D is the cultivar and planting density interaction

CV is the coefficient of variation

Table 4 PR>F-values from the analysis of variance for soil NO3, NH4, (mg/kg) and enzyme activity after 2005/06 growing season at Taung.

Treatments	NO_3 (mg/kg)	NH_4 mg/kg)	Enzyme activity (μg INF g^{-1})
Cultivar	0.012	0.890	0.266
Density	0.013	0.204	0.277
C x D	0.778	0.800	0.164
CV (%)	42.59	18.31	29.91

C X D is the cultivar and planting density interaction

CV is the coefficient of variation

Table 5 PR>F-values from the analysis of variance for soil NO_3^- and NH_4^+ (mg/kg) after 2006/07 growing season at Potchefstroom and Taung.

	Potchefstroom		Taung	
Treatments	NO_3^-	NH_4^+	NO_3^-	NH_4^+
Cultivar	0.847	0.306	0.063	0.750
Density	0.792	0.084	0.311	0.720
C x D	0.570	0.094	0.665	0.607
CV (%)	16.34	41.96	23.1	31.3

C X D is the cultivar and density interaction

CV is the coefficient of variation

Table 6 PR>F-values from the analysis of variance for maize grain yield (kg ha^{-1}), Stover yield (kg ha^{-1}), cob length(cm), plant height (PH) (cm), kernel number per cob, 100 kernels weight (g) and number of cobs, during 2006/07 growing season at Potchefstroom.

Trt	Grain yield	Stover	cob length	KNC	100 seed mass	PH
Cultivar	0.744	0.533	0.158	0.815	0.603	0.010
Density	0.331	0.493	0.019	0.072	0.041	0.012
CxD	0.047	0.428	0.049	0.649	0.028	0.044
CV (%)	33.5	37.45	12.74	19.3	15.49	10.3

C X D is the cultivar and density interaction

CV is the coefficient of variation

Table 7 PR>F-values from the analysis of variance for maize grain yield (kg ha^{-1}), Stover yield (kg ha^{-1}), cob length (cm), plant height(cm),kernel number cob, 100 grains(g) and number of cobs, during 2006/07 growing season at Taung.

Trt	Grain yield	Stover yield	cob length	KNC	100 seed	PH

	(kg ha^{-1})	(kg ha^{-1})	(cm)		mass (g)	(cm)
Cultivar	0.0205	0.573	0.017	0. 025	0.219	0.028
Density	0.0001	0.629	0.647	0. 278	0.926	0.379
CxD	0.3557	0.191	0.413	0.091	0.786	0.029
CV (%)	30.79	22.2	13.7	19.63	12.0	6.6

C X D is the cultivar and density interaction

CV is the coefficient of variation