THE EFFECT OF MAIZE-LEGUME CROPPING SYSTEM AND NITROGEN FERTILIZATION ON YIELD, SOIL ORGANIC CARBON AND SOIL MOISTURE

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DECLARATION

The experimental work presented in this thesis was carried out at three locations of Northwest province of South Africa (Potchefstroom, Taung and Rustenburg) from 2010/11 up to 2012/13 planting seasons. The research contained in this thesis was completed under the Professional Development Program (PDP) of Agricultural Research Council (ARC) while based at the Agricultural Research Council, Grain Crops Institute, Potchefstroom, 2520 as a student under the supervision of Dr Lawrence G. Owoeye, as ARC line manager and Professor Albert T. Modi. The research was financially supported from funds under ARC PDP and National Research Foundation (NRF) of South Africa respectively.

The contents of this work have not been submitted in any form to another University and, except where the text, the results reported are due to investigations by the candidate.

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ABSTRACT

Crop rotation and intercropping are regarded as better cropping in terms of yield improvement of both cereal and legume crops as compared to monocropping. A factorial experiment was carried out at three dryland localities of Northwest province (Potchefstroom, Rustenburg and Taung) from 2010/11 to 2012/13 planting seasons. The experiment consisted of three cropping systems, monocropping, intercropping and rotational cropping. Two rates of nitrogen fertilizer, zero and optimum levels based on soil analysis results prior to planting were applied on maize and cowpea plots. Soil moisture content was evaluated during three growth stages at different depths of the soil (0-15, 15-30, 30-60 and 60-90 cm) using gravimetric method. Parameters considered for the study included the followings: 100% tasseling/flowering, days to physiological maturity, plant height, number of leaves per plant, leaf area in maize, stem diameter in maize, ear length in maize, ear mass , kernel number per ear, hundred seed mass, grain yield in maize, LER, plant population at harvest and stover yield in maize, number of leaves and nodules per cowpea plant, pod length, seed per pod, pod mass at harvest, grain, field biomass yield at harvest, cowpea leaf, immature pod, seed protein content and maize seed protein, oil, starch and phosphorus content. The analysed soil chemical properties included soil organic carbon using Walkley Black method, soil Bray 1-P; N-NO_3, N-NH_4 and exchangeable K. Cropping system had significant effect ($P < 0.05$) on the growth and yield of maize. Cowpea-maize rotation and monocropping maize had tasseled earlier, reached days to physiological maturity earlier, had large leaf area, higher number of leaves per plant, ear mass, kernel number, seed mass, grain yield and stover yield. Maize-cowpea rotation and monocropping cowpea had significantly ($P < 0.05$) higher number of leaves per plant, seed per pod, pod mass, grain yield and field biomass yield than intercropped cowpea. Cropping system had significant effect ($P < 0.05$) on soil organic carbon; Bray 1-P and soil nitrate (N-NO_3). The interaction effect of cropping system on

cropping system x nitrogen x site on maize yield, cowpea growth, protein content and soil N-NO_3 contributed towards significant of this study.

The chapters of this thesis represent different studies presented as different articles. Chapter 1 is a general introduction to explain the study background and hypothesis. Chapter 2 is on the effect of maize-cowpea cropping system on soil moisture content. Chapter 3 is on crop rotation and intercropping cowpea with maize: maize growth and yield. Chapter 4 is on crop rotation and intercropping cowpea and maize: cowpea growth and yield. Chapter 5 is on the effect of crop rotation and intercropping on cowpea crude protein. Chapter 6 is on the maize seed quality in response to crop rotation, intercropping and nitrogen fertilization. Chapter 7 is on the effect of maize-cowpea cropping system on soil chemical composition. The last chapter 8 is a general discussion and conclusion.

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ABBREVIATIONS

Monocowpea = monocropping cowpea

Monomaize = monocropping maize

Rotacowpea = rotational cowpea

Rotamaize = rotational maize

Rust = Rustenburg

Potch = Potchefstroom

Zero N= zero nitrogen fertilizer

N-fertilization = nitrogen fertilization

LSD = least significant difference

SEM = standard error of means

MIC/zero-N = maize intercropping cowpea under zero nitrogen fertilizer

MIC/N-fert = maize intercropping cowpea under nitrogen fertilizer

Rotational C = rotational cowpea

Rotational M = rotational maize

Max T (ºC) = maximum temperature in decrees Celsius

Min T (ºC) = minimum temperature in decrees Celsius

mm = millimeters

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CHAPTER 1

GENERAL INTRODUCTION

Maize and cowpea are planted by small scale and commercial farmers in either monocropping, intercropping or rotational cropping as strategy for improving food security. Crop rotation is the growing of different types of crops in the same piece of land in different seasons (Liebman and Dyck, 1993). The benefits of crop rotation include the increased yield of maize and maize grown in rotation with early and medium maturity cowpea varieties increased yield benefits (Ennin *et al.,* 2004). Crop rotation represents a systems approach in crop production research, enabling the available natural resources to be preserved and more efficiently utilized (Feizabadi and Koocheki, 2012).

Crop rotation involving legumes improve soil properties and reduce mineral fertilizer requirements of cereal crops (Bagayako *et al*., 2000; Chan and Heenam, 1996). According to Tiessen (1988), significantly higher soil N levels were observed under rotations that included maize and legumes. Crop rotation influences N use efficiency and also affects the nitrogen availability to the plant (Lopez-Bellido and lopez-Bellido, 2001). In crop rotation experiments, a monoculture is generally compared to various crop sequences. In most cases the yields of cultivated crops are higher in crop rotation, compared to a monoculture under same conditions (Berzsenyi *et al*., 2000). Cropping in rotation was more effective than intercropping for maintaining soil N status (Baldwin, 2006).

Crop rotation can be considered as best strategy for yield improvement, but it has its own disadvantages as stated by Yilmaz *et al*. (2008) that, it requires increased expertise, equipment and different management practices. Certain insect pests and diseases may spread easily from one crop to the next though the crop residues (Yilmaz *et al*., 2008).

Intercropping is the growing of two or more crops in the same piece of land during the same growing season (Sharaiha and Gliessman, 1992). Intercropping is a widely used cropping practice in various ecozones of Africa, but due to increased market orientation in cowpea production, over the last years more and more area is replaced by monocropping, resulting in increasing problems with pests and diseases (Trenbath, 1993; Fininsa, 2001). Intercrops are better than monocrop cultures because they yield more, protect against risks of drought and pests, even out the distribution of labour requirements, and provide a more balanced human diet (Vandermeer, 1990).

According to Banik *et al*. (2006) the advantages of intercropping include soil conservation, lodging resistance, and weed control over the monocropping. Mpangane *et al*. (2004) reported that intercropping maize with cowpea is a common practice in smallholder farming systems. It was further indicated that, introduction of leguminous crop species into cropping systems had been recognised as an important approach to soil fertility improvement (Mpangane *et al*., 2004). Since intercropping increases light interception, it reduces growth of late emerging weeds (Takim, 2012).

Disadvantages of intercropping include the competition for light, water and nutrients between crops, which lead to reduction of yields (Cenpukdee and Fukai, 1992). A serious disadvantage of intercropping is due to different requirements for fertilizers, herbicides and pesticides of component crops. In the intercropping, mechanization is almost impossible (Vandermeer, 1990). The other disadvantage of intercropping cowpea with cereal crops is higher labour requirements during inter-row cultivation of crops. Farmers have to increase labour input for removing weed on intercropping rows with hand hoes (Osman *et al*., 2011).

1.1. The effect of planting date on maize-cowpea production

Planting date has a major effect on the yields of maize and cowpea (Sesay, 2000). Planting dates can change over time, due to changes in climate (Kucharik, 2006). According to Sacks *et al*. (2010) the relationships between planting date and climate for maize can be useful for estimating planting dates in regions. It was further reported that climate alone cannot fully explain farmer’s choices about when to plant their crops. According to Saseendran *et al*. (2005) planting date depends on the weather variability at the location and varies among years and locations. It was further reported that studies for determining planting date recommendations for a locality should be based on field experiments that have been done periodically with limited multiyear and multi-location replications (Saseendran *et al*., 2005).

1.1.1. Planting date and maize-cowpea growth

Fabunmi *et al*. (2012) reported that cowpea canopy height was significantly affected by planting date at two and five weeks after planting. Plant height of succeeding maize responded significantly to date of planting of preceding cowpea green manure at eight weeks after planting. According to Adipala *et al*. (2002), time of introducing cowpea into maize significantly affected the growth of cowpea. The reduction in the growth of cowpea was due to increased shading from the maize plants especially when cowpea was introduced at the fourth week. A study by Amujoyegbe and Elemo (2013) showed that the time of introducing cowpea in intercropping system had significant effect on canopy height of crops across seasons and locations. Early introduction of cowpea together with maize led to high cowpea canopy formation. A study by Aziz *et al*. (2007) showed that late planting of maize reduced vegetative growth because of less photosynthetic activity at later stages of plant growth. Late planting of maize terminated vegetative growth and resulted in shorter plant with fewer and smaller leaves.

1.1.2. Planting date and maize-cowpea yield

In the case of maize, yield decreased sharply as planting date was delayed, while yields of cowpea were higher with a later planting date (Ofori and Stern, 1987). According to Lawson *et al*. (2009) planting the two intercrop components the same day gave the highest maize grain yield. Amjadian *et al*. (2013) indicated that planting date significantly affected maize qualities such as number of rows, number of kernels, grain weight and grain performance. The delay in planting time decrease number of grains per maize plant, number of rows and seed performance. Myaka (1995) reported that yield of cowpea was not significantly different when sown with maize or two weeks after maize, while yield was 67% lower when sown four weeks compared with two weeks after maize. According to Mariga (1990) cowpea sowing date did not affect grain yield of the maize intercrop and the best intercropping treatment was simultaneous sowing.

1.2. Crop rotation and its advantages

A well planned crop rotation system that includes a legume crop will not only contribute to replenishing soil nutrients but also reduce the demand for chemical fertilizers (Baloyi *et al*., 2009). It will also help break the cycle of disease and pest build-up in the soil, a condition that characterizes monoculture. Reddy (2000) reported that many crops may have positive effects on the succeeding crops in a rotation, leading to greater overall production.

1.2.1. Crop rotation and soil fertility

Rotation may also give benefits in terms of improved soil quality, better distribution of nutrients in the soil profile and to increased biological activity (Ogungbile *et al*., 1998). According to Reeves (1997) long-term studies have consistently shown the benefit crop rotation on maintaining agronomic productivity by increasing carbon inputs into the soil. It was further indicated that even with crop rotation and manure additions, continuous cropping results in a decline in soil organic carbon. Lalfakzuala *et al*. (2008) reported that long term cropping systems can influence important soil properties such as soil organic matter and nutrient cycles within the soil profile. The positive effect of crop rotations on physical, chemical and biological soil properties are related to higher carbon inputs and diversity of plant residues returned to soil. The study of (Moore *et al*., 2000) indicated that crop rotation significantly affected soil biomass carbon.

1.2.1.1. Soil fertility and soil organic carbon

Soil organic carbon is an important indicator of soil quality because it influences soil structure. Soil structure affects soil stability as well as its capacity to hold water (Perucci *et al*., 1997). Sundermeier *et al*. (2004) reported that carbon is a key ingredient in soil organic matter. It was further highlighted that soil carbon sequestration is a natural, cost effective and environmentally friendly process. The soil carbon benefit of organic farming results from the fact that the system is based on inputs of organic matter to the soil and its decomposition by soil microbial activity. This releases nutrients for crop production and this process also produces humus which raises the soil carbon level. It was concluded that there is a positive association between soil carbon levels and soil microbial levels, because it is soil microorganisms that produce the humus (Sundermeier *et al*., 2004).

1.2.2. Rotation and soil nitrogen

Cowpea rotation can be considered to be an effective resource management technology in cereal based systems. Carsky *et al*. (2002) reported that leguminous rotation and fallows is the key to sustainable and productive soil management. They require less N for growth and produce high protein products. The use of legumes replaces a small part of the N fertilizer required by subsequent cereals in a rotation. According to Ennien *et al*. (2004) the amount of N contributed to the soil by a legume for the benefit of other crops grown either in association or in rotation depends on the total amount that is fixed and the proportion of fixed

N that is removed from the field in the harvested seed and straw. In the absence of the fertilizer application, the rotation of maize with legumes, especially the pigeon pea, could be considered as an alternative cropping that returned large quantities of residue to the soil, sustained maize growth and minimized soil carbon loss (Adiku *et al*., 2009). To attain highest productivity levels, it is necessary to combine rotation systems with mineral N fertilizer (Iwuafor *et al*., 2006). According to Altieri (1995) organic rotation are divided into phases that increased the level of soil nitrogen and phases that deplete it. Rotation provides the basis for forward planning of nitrogen supply, necessary in the absence of soluble nitrogen fertilizer (Watson *et al*., 1996). Qureshi (1990) reported that incorporating maize crop residue increased the content of available K, Ca, Mg, P, organic carbon and total N in the soil. Crops such as cowpea, mung bean, soybeans and groundnuts commonly accumulate 80-250 kg N ha^{-1} (Donald *et al*., 1963; Norman, 1996; Weber, 1966). Nelson and Spaner (2010) reported that systems that have reduced tillage, diverse crop rotations or intercrops and low application of inorganic fertilizer tend to encourage a large and diverse microbial community. It was further indicated that well-managed conventional systems with minimum tillage and inorganic crop inputs can be as effective as organic systems in encouraging soil biological fertility.

Sarr *et al*. (2008) reported that soil microorganisms compete with plant for available nitrogen, which results in a decrease in nitrogen availability for the first crop. The decomposition of these microorganism releases substantial available nitrogen for the following crops.

According to Ouma and Jeruto (2010) in intercropping, nitrogen fixation by the legume is not sufficient to maintain soil fertility. If chemical fertilizers are applied, it is not necessary to use nitrogen fertilizer on the cereal crops. It was further indicated that fertilizers are more efficiently used in an intercropping system, due to the increased amount of humus and the different rooting systems of the crops as well as differences in the amount of nutrient taken up.

1.2.3. Crop rotation and yield improvement of crops

Yadav *et al.*(1998) reported that in a crop rotation, essential plant nutrients are absorbed by the crop plants in a balanced manner as the nutrient requirement of crops are different, some taking up more of one kind of nutrient than another. A process of single sided depletion may therefore take place unless a change of crops or rotation is practiced. Yadav *et al.* (1998) further highlighted that legumes assimilating nitrogen from the atmosphere and enriching the soil with their root system form an important component in the rotation. Crops sown under rotation have to be selected in such a way that they are able to suppress the weeds. They further indicated that, the yield increasing effects of crop rotations, especially where legumes are involved have been attributed to a number of factors, including the improvement of soil fertility, enhancement of balanced nutrient removal from the soil and improvement of soil physical properties. Other benefits of crop rotation include soil conservation, organic matter restoration and pests and disease control. The value of crop rotation is measured by its effect on land productivity and its economic return (Ogungbile *et al.*, 1998). According to Adiku *et al.* (2009) maize rotated with cowpea or pigeon pea produced similar maize biomass of 8.0 t/ha per year, but with higher variability for the maize-cowpea rotation. Biomass produced by cowpea or pigeon pea were 4.0 and 8.0 t/ha per year respectively. Rao and Mathuva (2000) reported that maize-cowpea sequential and pigeon pea/maize intercropping systems produced respectively higher maize yields than continuous sole maize, but maize-pigeon pea rotation yielded only marginally better. According to Hardter *et al.* (2008) higher maize yields were obtained in maize/cowpea rotation, which in contrast to the other cropping systems did not show any reductions in yields over years. The parameters of the study indicated low productivity of maize mono-cropping, clearly demonstrating that crop sequence as well as fertilizer application must be considered as important for maintaining high production levels.

Adetunji (1996) reported that maize grain yields were significantly increased when cowpea was rotated with maize, either as mono-crop or intercrop, as compared with continuous maize. Maize-cowpea rotation can provide a sustainable alternative to chemical N fertilizers and can supply most or some of the maize N requirements. Nel and Loubser (2004) reported that higher yields associated with rotated crops will increase the cost of activities such as harvesting. They indicated that, weed and pest control costs are less on rotated than mono-cultured crops which will increase the net return. It was further highlighted that the savings on the inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates (Nel and Loubser, 2004).

Rafael *et al.* (2001) reported that cereal-legume rotation was the most effective of all rotations tested. Cereal yields were more stable for all N fertilizer rates. It was further reported that monoculture in their study prompted consistently lower yields than two year rotations, and also led to accumulation of soil nitrate, owing to lower N use efficiency (Rafael *et al.*, 2001).

Adiku *et al.* (2009) reported that when no fertilizer was applied to maize, the yield for the maize legume rotation treatments was no better than that for the maize grass fallows. It was reported that the differences in maize response to the different rotations could also be attributed to the differences in biomass additions to the soil. Iwuafor *et al.* (2006) reported that the main effect of rotation on exchangeable cations was highly significant with all rotation systems performing better than the continuous maize. Unfertilized maize grain yield was significantly higher following the two cowpea varieties than maize and natural fallow. In that study, there was no interaction between rotation and fertilizer effects, which indicates that other non-N effects were equally important.

The study showed that crop rotation involving grain legumes is a viable management option that helps increase maize yield and can substitute the unproductive fallow system traditionally used for soil fertility maintenance. Ennin *et al.* (2004) reported that medium maturity cowpea in rotation with maize resulted in significantly higher maize grain yields than continuous maize with or without applied N and had N credits greater than 90 kg N ha^{-1}. They further highlighted that the benefits of legumes in cropping systems is through biological nitrogen fixation (BNF), which can be as much as 450 kg N ha^{-1} although as much as 201 kg N ha^{-1} per season has been reported. Soybean usually fixes between 50 and 150 kg N ha^{-1}. It was also indicated that, soybean and groundnut of both early and later maturity did not have yield benefits to maize in rotation when no N was applied. Maize planted after early maturity soybean resulted in a significant decrease in maize grain yield at 0 N and negative N credits to maize (Ennin *et al*., 2004).

1.3. Cowpea and soil nitrogen fixation

Dadson and Acquaah (1984) reported that in N deficient soils, smaller starter doses of applied N may stimulate nodule formation and enhance the grain yield of legumes. The low soil N status of the soils is expected to encourage a positive response to Rhizobium inoculation particularly in the presence of applied phosphorus. Nodulation of faba bean was markedly restrained by N fertilization at the later growth stage of faba bean but facilitated remarkably by inoculation, and the facilitation of intercropping on nodulation was erratic (Omar and Abd-Alla, 1994).

Sangakkara and Marambe (1989) reported that inoculation increased nodulation of bush beans and to a lesser extent of mungbean. This effect was more evident with time. Nodulation was reduced in the presence of nitrogen fertilizer, and the effect was more pronounced in the extensively nodulating species, mungbean. Nitrogen and nodulation increased yield of both species. The study indicated the inability of bush beans to meet all nitrogen requirements by nodulation and nitrogen fixation alone. This suggests the need for some fertilizer nitrogen for tropical legumes, in addition to inoculation, to obtain yields (Sangakkara and Marambe, 1989). Otieno *et al*. (2007) reported that when sufficient levels of nitrogen are present in the soil, nodulation is inhibited. Nitrogen fertilizer application significantly reduced the number of nodules and nodule dry weight per plant in most species during long rains.

They further indicated that, the addition of 20 kg N ha^{-1} as ammonium nitrate depressed nodulation and nitrogen fixation in soybean. Nitrogen is known to impact negatively on nodulation but phosphorus has been reported to improve nodulation. Rhizobia inoculation increased number of nodules and nodule dry weight per plant for most species but the increase in the nodulation was neither translated to dry matter accumulation in the shoot and root nor to the yield and yield components (Otieno *et al*., 2007).

Cartwright and Snow (1962) reported that the urea treatment resulted in a delay in nodulation so that the number of nodules at the first sampling (four weeks) were reduced, while numbers at later samplings were higher since nodulation had been delayed until the root system was larger and provided a greater number of potential nodule sites. The authors further indicated that, urea treated plants showed reduced nodulation throughout the six week experimental period. It was highlighted that the advance effects on nodulation cannot be due to high concentration of combined nitrogen in the rooting medium, but it is suggested that they derive from a high level of nitrogen within the plant (Cartwright and Snow, 1962).

Davis *et al*. (1991) reported that cowpea, like all legumes forms a symbiotic relationship with a specific soil bacterium (Rhizobium spp). Rhizobium makes atmospheric nitrogen available to the plant by a process called nitrogen fixation. Excess nitrogen promotes lush vegetative growth, delays maturity, reduce seeds yield and may suppress nitrogen fixation. Cowpeas perform well under low N condition due to a high capacity of N fixation. A starter N rate of around 12.25 kg ha^{-1} is sometimes required for early cowpea plant development on low N soils (Davis *et al*., 1991).

Geetha and Varughese (2001) also reported that even though cowpea has the ability to fix atmospheric nitrogen, it requires a starter dose of nitrogen for early growth and establishment. Higher level of nitrogen tended to reduce the pod yield in their study. The authors highlighted that the reduction in yield at higher dose of nitrogen might be due to the excessive vegetative growth at the expense of pod production (Geetha and Varughese, 2001).

Abayomi *et al*. (2008) reported that a parameter such as plant height; number of branches per plant, number of pods per plant, pod weight and shelling percentage were significantly improved by the application of nitrogen fertilizer and hence significant increase in grain yield. It was concluded that the application of inorganic fertilizer to cowpea is beneficial, although in a small quantity of 30 kg N ha^{-1}.

1.3.1. Soil nitrogen and maize production

Gungula *et al*. (2005) reported the significant differences observed in total leaf number among N rates, which is the indication that the number of leaves produced by maize plant is affected by N rates. Increasing the N rates resulted in more leaves produced per plant with the highest mean values in most cases at 120 kg N ha^{-1}. They further indicated that higher N rates enhanced the vegetative growth of the maize and increased the source capacity of the plants by the number of leaves produced per plant. By increasing the level of N in the soil, there will be more green leaves maintained on the plants. It was also indicated that, since there are more leaves produced at higher N rates, those higher N rates will have higher photosynthetic capacity than the lower N rates.

Ding *et al*. (2005) reported that N deficiency decreased grain yield and plant weight. The response of grain yield to N deficiency was associated with much larger effects on biomass production than the harvest index. They further indicated that, different responses of grain yield to N deficiency between hybrids were mostly due to their different rate of accumulation of dry matter after anthesis. Leaf area may be decreased by N deficiency depending on the severity. Dry matter production after flowering of the N deficient plant was significantly lower in the study by Ding *et al*., (2005).

Thomison *et al*. (2004) reported that split applications of N increased grain protein concentration but had little or no effect on yield. Grain oil concentration was not influenced by the timing of N application and responded to N rate only. Their study demonstrated that N management will be an important factor in maximizing the grain protein of nutritionally enhanced maize. Feinerman *et al*. (1990) reported that late nitrogen application at tassel emergence did not increase corn yield. If applying nitrogen as late as tassel emergence, it is important that the fertilizer be activated either by rainfall or irrigation or soon as possible for maximizing plant availability of the nitrogen fertilizer and minimizing yield loss.

They further indicated that nitrogen fertilizer application as late as tassel emergence may increase corn yield if the plant is nitrogen deficient. Sharifi and Taghizadeh (2009) reported that maximum maize plant height of 204.6 cm was obtained with the highest nitrogen level of 240 kg N ha^{-1}, while the least value of 181 cm was recorded at the lowest nitrogen level of 0 kg N ha^{-1}. It was highlighted that across nitrogen levels, maximum number of kernel per ear (668) was recorded at 240 kg N ha^{-1} and minimum of 300.3 at 0 kg N ha^{-1}. The number of kernel per ear increased with increasing nitrogen level.

It was revealed that nitrogen levels influenced significantly the cob length of maize hybrid. Ear length generally decreased with decrease in nitrogen level. Nitrogen levels and maize hybrids did not show any significant variation in respect of number of ears per plant (Sharifi and Taghizadeh, 2009).

1.4. Intercropping and its advantages

Francis and Decoteau (1993) reported that intercropping offers farmers the opportunity to engage nature's principle of diversity on their farms. Intercrops can be more productive than growing pure stands. Pest management benefits can also be realized from intercropping due to increased diversity (Mousavi and Eskandari, 2011). They further indicated that, planting intercrops that feature different development periods takes advantage of variations in peak resource demands for nutrients, water and sunlight.

Altieri and Leibman (1994) reported that having one crop mature before its companion crop lessens the competition between the two crops. Selecting crops or varieties with different maturity dates can also assist staggered harvesting and separation of grain commodities. They further indicated that, the most important reasons to grow two or more crops together are the increase in productivity per unit of land.

Willey (2006) reported that the biological basis for intercropping advantages include the use of resources such as light, plant nutrients and water, N relations in legume/non-legume combinations and yield stability. Another advantage of intercropping is that the soil is used more efficiently (Eskandari *et al*., 2009). A mixture of various crops will often give a better coverage of the soil leaving less space for the development of weeds. Risch (1983) reported that many pests and diseases multiply more rapidly in monoculture than in a mixed crop. In a monoculture, insects can disperse easier and faster. When other crops are present in the field the insects need more time to search for the host plant.

1.4.1. Types of intercropping

Intercropping is the space-dependent form of multiple cropping and is the growing of two or more crops simultaneously on the same field (Marshall and Brown, 1974). Intercropping is divided into four sub-categories: (i) mixed intercropping, which is the growing of two or more crops simultaneously with no distinct row arrangement. (ii) Row intercropping is the growing of two or more crops simultaneously where one or more crops are planted in rows. (iii) Strip intercropping is the growing of two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically. (iv) Relay intercropping is the planting of a second crop into a standing crop at the time when standing crop is at its reproductive stage but before harvesting (Marshall and Brown, 1974).

1.4.2. Intercropping and Land equivalent ratio (LER)

Hardter *et al*. (2008) reported that maize yields of the intercropping systems, especially of maize cowpea mixed cropping, were significantly lower than in sole cropping. They further indicated that, by reducing the seeding rates of each crop; the crops have a chance to yield well within the mixture. It is suggested that the most important practical situation is where intercropping is called on to produce higher total crop yields than where each crop component is grown separately. It was concluded that LER (Land equivalent ratio) is probably the most useful term at present available for assessing the advantage of intercropping.

LER is likely to be lowered towards unity and is expressed in the following equation:

$$\text{LER} = \frac{\text{Cowpea intercrop yield}}{\text{Cowpea sole yield}} + \frac{\text{Corn intercrop yield}}{\text{Corn sole yield}}$$

When LER ≤ 1, intercropping is disadvantageous while LER ≥ 1 implies intercropping is advantageous (Benites *et al*., 1993). Better use of growth resource as a result of the complementary effect between component crops is considered to be a major source of yield advantage from intercropping (Willey, 2006). Zuo and Zhang (2009) reported that monocropping has maintained crop productivity through heavy chemical inputs including the application of fertilizers and pesticides. Monocropping has therefore resulted in substantial eutrophication, environmental pollution, a food security crisis and economic burdens on the farmer.

1.4.3. Intercropping and yield of crops

Newman *et al*. (1997) reported that intercropping with maize in sub-arid regions is a way to grow a staple crop while obtaining several benefits from the additional crop. Intercropped maize may produce LER of 0.58 the yield of monocropped maize and intercropped beans may produce 0.67 LER the yield of monocropped beans. They further indicated that, when nitrogen fertilizer is not applied; intercropped legume will fix most of their nitrogen from the atmosphere and not compete with maize for nitrogen resources. High densities of maize maximized maize yield and calorie production, but high densities of beans maximize financial return (Ullah *et al*., 2007).

Chabi-Olaye *et al*. (2005) reported that maize monocrops had more stems tunnelled and more cob damage than intercropped maize. Each percentage increase in stem tunnelling under monocrop lowered maize grain yield by 1.10 and 1.84 g per plant. Maize yield losses due to stem borer were 1.8-3.0 times higher in monocrops than in intercrops. Khandaker (1994) reported that intercropping of maize and cowpeas is beneficial on nitrogen poor soil. The author reported that, maize yields were significantly not affected by intercropping with cowpea in that study. It was reported that, cowpeas planted three weeks after maize had significantly reduced yields during previous studies and therefore it was recommended to plant cowpeas with maize simultaneously (Khandaker, 1994).

1.4.4. Intercropping and soil structure improvement

Dahmardeh *et al*. (2009) reported that intercropping of maize and cowpea is more economical than maize monocropping when phosphorus fertilizer is not applied. Maize-cowpea intercropping increases green fodder yield and forage quality of maize. They indicated that, maize-cowpea mixture are advantageous compared to both sole crops of maize and cowpea.

Olufowote and Mc Connell (2002) reported that incorporating cowpea in the cropping system either as a sole crop or intercrop with cereal will go a long way to improve the fertility of those degraded soils or is crucial for sustainable crop productivity.

They indicated that, where soil degradation is a major constrain to crop production, inclusion of cowpea into the cropping system is crucial as it helps to replenish soil nitrogen. According to Khandaker (1994) inclusion of cowpea in the cropping system will improve the nutrition of the people, increase the feed quality of livestock and contribute to soil fertility maintenance. This will further lead to increased food security and reduced environmental degradation.

According to Latif *et al*. (1992) improvement of soil structure in maize plots associated with increasing N application was the results of increased maize-root residues. Legumes intercropped with maize and N fertilization may be helpful in maintaining and improving the soil organic matter and there by improving the soil structure. According to Ahmad *et al*. (2013) monocropping system had negative impacts on soil physical properties and structure and intercropping system is the better option to address problem of soil structure. Intercropping is now becoming more important to improve soil quality and increase crop productivity (Li *et al*., 1999)

1.5. Nutritional value of crops

Protein is reported to be the major components affecting function properties of food material (Oyarekwa and Adeyeye, 2009). Water absorption capacity is attributed to protein content of food material (Fleming *et al*., 1974). According to Sefa-Deden and Afaokwa (2001), addition of cowpea improved the water absorption potential of maize; this led to increase protein content. Cereals such as maize are widespread used in livestock nutrition for their high production and low cost, they have low nutritional value due to their forage quality (Ghanbari-Bonjar, 2000).

1.5.1. Crude protein content of cowpea

Evans and Boulter (1974) found that the range of crude protein of 79 cowpea varieties was 21 to 34% and stated that due to the wide range screening for higher protein containing cowpea varieties were likely to be successful. Cowpea meal is a valuable protein source which can contribute towards overcoming the predicted protein shortage by supplying protein, produced in the arid agronomical areas of South Africa (Nell *et al*., 1992). Cowpea contains about 24% protein, 62% soluble carbohydrates and small amounts of other nutrients. The high protein content represents a major advantage in the use of cowpea in nutritional products and compensate for the large proportion of carbohydrate often ingested in African diets (Central Bank of Nigeria, 1997 and 1998). Sebetha *et al*. (2010) reported that cowpea leaves from sole crops plots had higher protein content than those from intercrop. It was reported that cropping systems during vegetative stage had no significant effect on the protein content of cowpea green pods. It was concluded that when cowpea is grown as vegetable crop, it should be planted as sole crop and harvested since higher protein content of both leaves and green pods will be obtained than when intercropped with cereal crops. The increase in crude protein content of cowpea can be attributed to production of growth enzymes (Sunday *et al*., 2001).

1.5.2. Crude protein content of maize and the influence of legume intercropping

Eskandari and Ghanbari (2009) reported that total nitrogen uptake by maize was significantly affected by cropping system. They further reported that nitrogen uptake by maize in intercropping was significantly greater than for the sole maize. Crude protein content of maize in intercrops was significantly greater than in maize sole crop. Therefore, forage quality of maize was high in intercrops compared with its sole crop. Forage quality of maize was improved by intercropping due to more nitrogen availability for maize in intercropping (Eskandari and Ghanbari, 2009). Cereal grains have a low protein concentration and that protein quality is limited by deficiencies in some essential amino acids, mainly lysine (Bressani, Breuner and Ortiz, 1989).

Dzowela (1987) reported that the inclusion of the climbing forage legumes resulted in a maize legume and stover product higher in crude protein content. The climbing forage legumes were intact on to stover at the time of harvesting the stover and contributed to the high crude protein contents. Haque *et al*. (1986) reported that protein yield per hectare is increased by intercropping cereals and forage legumes. Protein yield of cereal crops such as sorghum was higher when intercropped with fodder cowpea than with grain legumes grown to maturity. Higher crude protein yields were obtained from treatments in which two rows of sorghum and one row of lablab were planted, but with maize the highest protein yields occurred where cereal and legume were mixed and broadcast (Haque *et al*., 1986). Iqbal *et al*. (2006) reported that both the interactive and main effects of fertilizer and intercropping on crude protein content of maize and legume mixed forage was significant. The highest crude protein content of 12.98% was recorded for the crop fertilized with 150-100 kg NPK ha^{-1} and intercropped with cowpea.

The lowest crude protein of 7.5% was recorded for the maize crop grown alone with no fertilizer. Gunasena *et al*. (1978) reported that the crude protein content of maize increased with N under mono-cropping and intercropping. The authors indicated that, in mono-cropped maize crude protein content ranged from 8.74 to 8.92 in experiment one and from 8.5 to 8.77 in experiment two at zero and 50 kg N respectively. Under intercropping, the crude protein content of maize increased by 4.2% and 7% in experiment one and experiment two with 25 kg N. It was highlighted that although intercropping tended to depress the crude protein content of both maize and soybean, the crude protein harvest of combined maize-soybean was higher than that of the mono-cropped system (Gunasena *et al*., 1978).

1.6. Conclusions

The literature reviewed the benefits of maize-legume intercropping and rotation on grain yield. In most study revealed by literature, intercropping and crop rotation were studied separately, not compared in relation to nitrogen fertilization. The focus on the current was on the comparison of maize-cowpea rotation and intercropping in relation to nitrogen fertilization. Soil moisture retention was compared between monocropping maize and cowpea, intercropping maize-cowpea and in rotational plots of maize and cowpea. The interaction effects of cropping system, site and nitrogen fertilizer on the quality of maize and cowpea form part of this study. The soil chemical properties as affected by the interaction of cropping system, site, nitrogen fertilizer and season were also studied. The yield and growth of maize and cowpea under monocropping, intercropping and rotation were also the focus of the study. The specific objectives of the study were:

1. To establish the interaction effect of site, cropping system and nitrogen fertilization on maize and cowpea biomass production and yield components.
2. To establish the effect of maize-legume cropping system and nitrogen fertilization on soil chemical properties, moisture content and soil organic carbon.
3. To evaluate the effect of cropping system and nitrogen fertilization on the quality of cowpea (crude protein) and maize seed.

The problem statement of the study:

The interaction effects of cropping systems x site x nitrogen fertilizer x season on maize-cowpea growth were not studied extensively during previous studies. The yield and growth of maize-cowpa had been studied separately under intercropping and rotational cropping systems and were not compared in relation to nitrogen fertilization. The quality of both cowpea and maize were not evaluated extensively in previous studies under the influence of cropping system, site, season and nitrogen fertilizer interactions.

The hypotheses of the study were:

1. Cropping systems such as intercrop and rotation in relation to nitrogen fertilization will have more soil moisture content compared to monocropping and zero nitrogen fertilization.

2. Cropping systems such as intercrop and rotation in relation to nitrogen fertilization will have higher maize-cowpea growth, yield and biomass compared to monocropping and zero nitrogen fertilization.

3. Cropping systems such as intercrop and rotation in relation to nitrogen fertilization will have higher maize-cowpea quality compared to monocropping and zero nitrogen fertilizer.

4. Cropping systems such as intercrops and rotation with legumes will have more soil nitrogen compared to monocropping systems on maize.

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CHAPTER 2

THE EFFECT OF MAIZE-COWPEA CROPPING SYSTEM ON SOIL MOISTURE CONTENT

Abstract

Soil moisture is the most important factor controlling germination, root growth and emergence. The experimental design was factorial experiment laid out in RCBD with three replicates. The experiment consisted of five cropping systems, which were monocropping cowpea, monocropping maize, rotational maize, rotational cowpea and intercropping maize-cowpea. The three growth stages compared in this study were before tasseling/flowering, during tasseling/pod formation and during physiological maturity of maize and cowpea. The three sites of data collection were Potchefstroom, Taung and Rustenburg. Soil misture content was determined from the depth of 0-15, 15-30, 30-60 and 60-90 cm. The method used to determine moisture content was Gravimetric method. The growth stage before tasseling/flowering in maize/cowpea had significantly ($P < 0.05$) higher moisture content of 10.15, 10.84, 12.53 and 13.25% at the depth of 0-15, 15-30, 30-60 and 60-90 cm respectively. Soil collected at Rustenburg and Potchefstroom had significantly ($P < 0.05$) higher moisture content of 13.54 and 10.24; 15.87 and 10.91; 18.26 and 12.84; 18.44 and 14.47% at the depths of 0-15, 15-30, 30-60 and 60-90 cm respectively. Monocropping cowpea plots had significantly ($P < 0.05$) higher moisture content of 12.36% than other cropping systems at the soil depth of 30-60 cm. The interaction effect of growth stage x site x season on soil moisture content at different soil depths contributed significantly to the significant of this study, with the implication that, soil moisture availability depends on stages of crop growth under different sites with different climatic conditions.

Keywords: Crop rotation, growth stages, intercropping, soil moisture.

2.1. Introduction

Soil moisture conservation is one of the cardinal principles of soil management in rainfed areas with considerable potential for increased productivity. Moisture retention affects soil quality and plant moisture content of soil is one of the essential parameter that determines soil characteristics (Nyatuame and Nartey, 2013). Sandy soil has poor physical property, low water retention, low organic matter and high infiltration (Abdel-Nasser *et al*., 2007). It was further indicated that soil with high percentage of organic matter and natural deposits rich in clay content caused an increase in water holding capacity and reduction in evaporation (Parikh and James, 2012). The soil's ability to retain water is strongly related to particle size (Leeper and Uren, 1993). Water molecules hold more tightly to the fine particles of a sandy soil, so clay generally retains more water (Leeper and Uren, 1993).

Crops such as maize have different responses to water deficit according to their developmental stages (Cakir, 2004). During stem elongation of maize (after floral initiation), leaves and stems grow rapidly, requiring adequate supplies of water to sustain rapid organ development (Muchow, 1989). Moisture shortage was damaging to grain yield, if it occured early in the growing season, at flowering and during grain filling (Heisey and Edmeades, 1999). Cowpea can tolerate drought stress at the vegetative stage, and recover when water is available at the reproductive stage to produce seed yield equivalent to unstressed plants. Drought stress at the flowering or pod filling stage of cowpea reduce yield (Akyeampong, 1985). Excess water may also limit yields through nutrient losses in soil (Nandwa and Chege, 1996).

Crop canopy coverage conserves soil moisture, since shaded soil surface receives very little radiation and its temperature becomes lower than exposed soil (Hsiao and Xu, 2005). Intercropping improved the yield of companion crops by conserving soil moisture and making the environment more conducive for plant growth and development (Nedunchezhiyan *et al*., 2010). Cereal-legume use water more efficiently than monocropping cereal (Morris and Garrity, 1993). Soil moisture was lowest at sole maize and highest at sole cowpea (Ghanbari *et al*., 2010). The interaction effects of site, cropping system, growth stage and nitrogen fertilization on soil moisture content were critically evaluated. The objective of this study was to determine the effect of cropping system, growth stage, site and nitrogen fertilization on soil moisture content.

2.2. Materials and methods

2.2.1. Experimental sites

The study was conducted at three dryland localities. The department of agriculture experimental station in Taung situated at 27^{0} 30′S and 24^{0} 30′E and Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^{0} 26′S and 27^{0} 26′E. The Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg is situated at 25^{0} 43′S and 27^{0} 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*. 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*. 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*. 1968).

2.2.2. Experimental design

The experiment commenced in 2010/11 planting season, and the data considered were collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in RCBD with three replicates. The experiment consisted of five management systems, which were monocropping cowpea, Monocropping maize, rotational maize, rotational cowpea and intercropping maize-cowpea. The three growth stages compared in this study were (V10/Vn) before tasseling/flowering, (VT/R4) during tasseling/pod formation and during (R6/R8) physiological maturity of maize and cowpea. The results of soil analysis performed before planting indicated the amount of 5, 8 and 6.5 kg N ha^{-1} available at Potchefstroom, Rustenburg and Taung respectively. Based on previous studies performed on the selected sites, the optimum N rate to be applied on maize was 100 kg ha^{-1} at Potchefstroom and Rustenburg, while at Taung was 120 kg ha^{-1}. The optimum rate to be applied on cowpea was 25 kg ha^{-1} at Potchefstroom and Rustenburg, while at Taung was 30 kg ha^{-1}. Based on the above information, the amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1} were applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. The amount of 0 and 20; 0 and 17; 0 and 23.5 kg N ha^{-1} were applied on cowpea plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

2.2.3. Data collection, laboratory procedure and analysis

In this study, the soil moisture content was evaluated up to 60 cm deep in five cropping systems at different sites in relation to nitrogen fertilization. The evaluation was performed at different growth stages of maize and cowpea. Soil samples were collected at the depth of 0-15, 15-30, 30-60 and 60-90 cm during V10/Vn before (tasseling/flowering), during VT/R4 (ear/pod formation) and during R6/R8 (physiological maturity) stages of maize-cowpea. Soil samples were put inside plastic bags during collection at the field and were kept at cold room to avoid moisture loss from soil samples. Gravimetric water content (GWC) method was used to determine moisture content (Black, 1965). Each porcelain tin was weight and recorded and tarred before putting soil inside. Soil of 10 grams soil per tin was used. Samples were oven dried at 105°C for 24 hours. The samples were returned to the oven to dry for several hours, until there was no difference between any two consecutive measurements of the weight of dry soil + tare. GWC is calculated using the formula as:

$$\text{GWC} = \frac{(\text{Weight of wet soil + tare}) - (\text{Weight of dry soil + tare})}{(\text{Weight of dry soil + tare}) - (\text{tare})}$$

Analysis of variance was performed using GenStat 15th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered to be statistically significant (Gomez and Gomez, 1984).

Table 2.1. Soil physical properties of three sites collected before planting of trial.

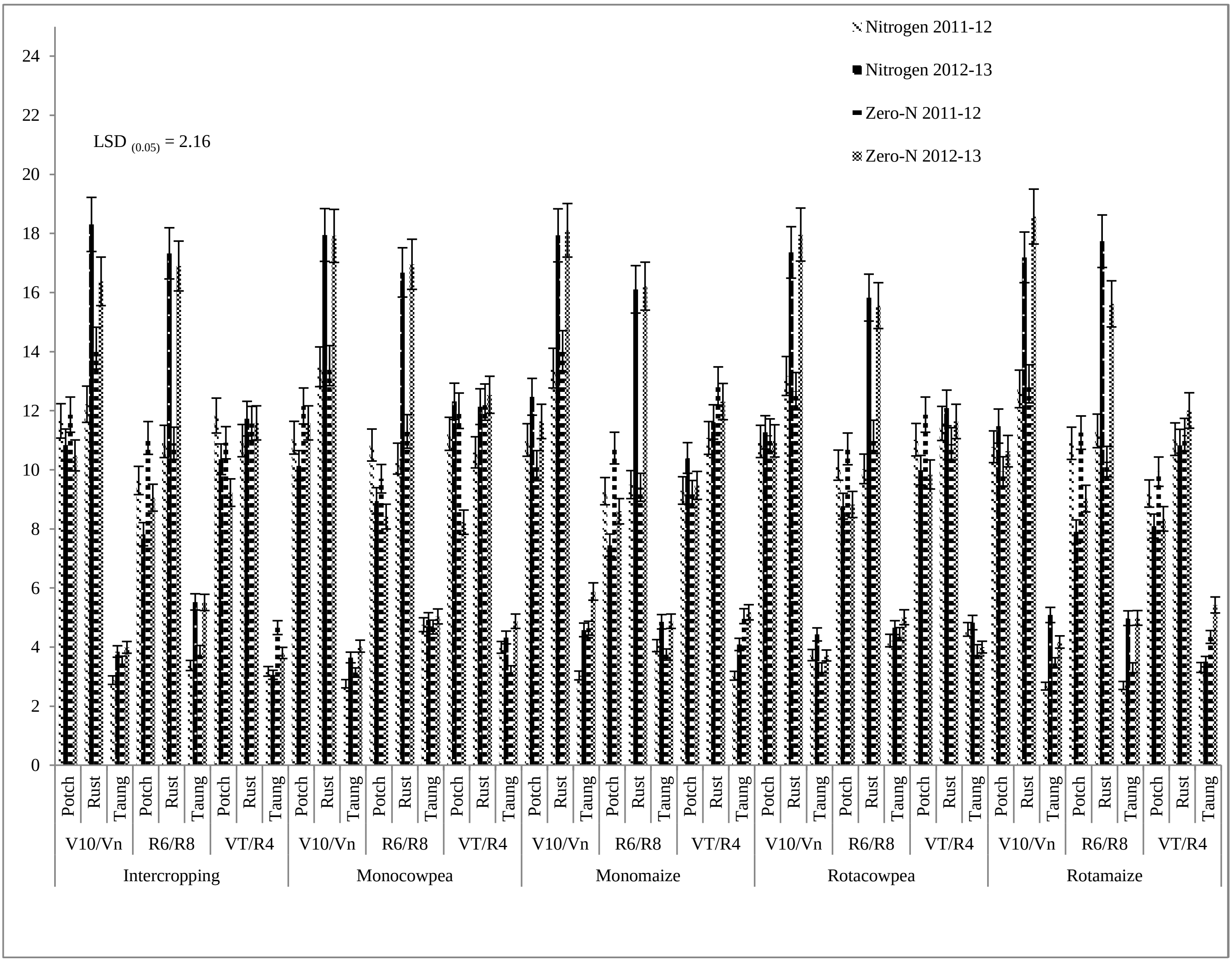
		Soil depth	
Site	Physical properties	0-15 cm	15-30 cm
Potchefstroom	% Sand	58	58
	% Silt	12	13
	% Clay	30	29
Taung	% Sand	91	91
	% Silt	1	1
	% Clay	8	8
Rustenburg	% Sand	44	42
	% Silt	7	8
	% Clay	49	50

2.3. Results

2.3.1. Soil moisture content at the depth of 0-15 cm

Growth stage had significant effect ($P < 0.001$) on soil moisture content at the soil depth of 0-15 cm (Figure 2.1 and Appendix 2.1.A). The growth stages of before tasseling/flowering (V10/Vn) and physiological maturity (R6/R8) in maize/cowpea had significantly ($P < 0.05$) higher moisture content of 10.15 and 9.14% respectively than soil collected during ear/pod formation stage (VT/R4). Site also had significant effect ($P < 0.001$) on soil moisture content. Soil collected at Rustenburg and Potchefstroom had significantly ($P < 0.05$) higher moisture content of 13.54 and 10.24% respectively than soil collected at Taung. Season also showed significant effect ($P < 0.001$) on soil moisture content. The soil collected during 2012/13 planting season had significantly ($P < 0.05$) higher soil moisture content of 9.90% than soil collected during 2011/12 planting season. The interaction of growth stage x site; growth stage x season; and site x season ($P < 0.001$) had significantly affected soil moisture content at the depth of 0-15 cm. The interaction of growth stage x site x season ($P < 0.001$) also had significantly affected soil moisture content.

Figure 2.1. The interaction effects of cropping system, growth stage, site and N fertilization on soil moisture content in percentages at the depth of 0-15 cm.

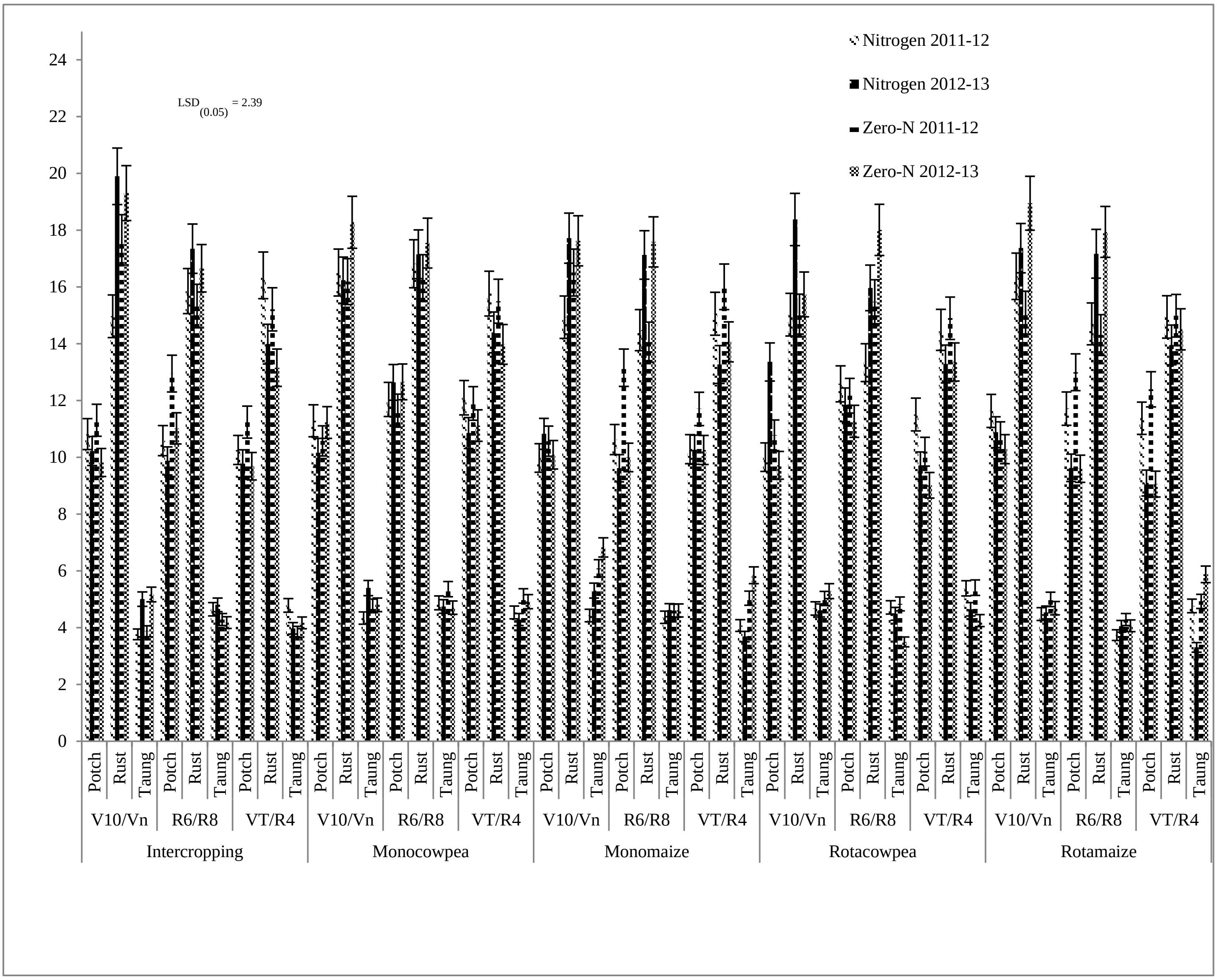


V10/V(n) = before tasseling of maize/ flowering of cowpea, R6/R8 = during physiological maturity of maize/cowpea, VT/R4 = during maize ear/cowpea pod formation, Rust = Rustenburg, Potch = Potchefstroom, Monocowpea = monocropping cowpea, Monomaize = monocropping maize, Rotacowpea = rotational cowpea, Rotamaize = rotational maize.

2.3.2. Soil moisture content at the depth of 15-30 cm

Growth stage had significant effect ($P < 0.001$) on soil moisture content at the depth of 15-30 cm (Figure 2.2 and Appendix 2.1.B). The growth stages before tasseling/flowering (V10/Vn) and physiological maturity (R6/R8) in maize/cowpea had significantly ($P < 0.05$) higher moisture content of 10.84 and 10.69% than soil collected during ear/pod formation stage (VT/R4). Site also had significant effect ($P < 0.001$) on soil moisture content. Soil collected at Rustenburg and Potchefstroom had significantly ($P < 0.05$) higher moisture content of 15.87 and 10.91% than soil collected at Taung. The interaction of cropping system x site ($P = 0.041$); growth stage x site; and growth stage x season ($P < 0.01$) had significant effect on soil moisture content. The interaction of site x season; and growth stage x site x season ($P < 0.01$) also had significantly affected soil moisture content.

Figure 2.2. The interaction effects of cropping system, growth stage, site and N fertilization on soil moisture content in percentages at the depth of 15-30.

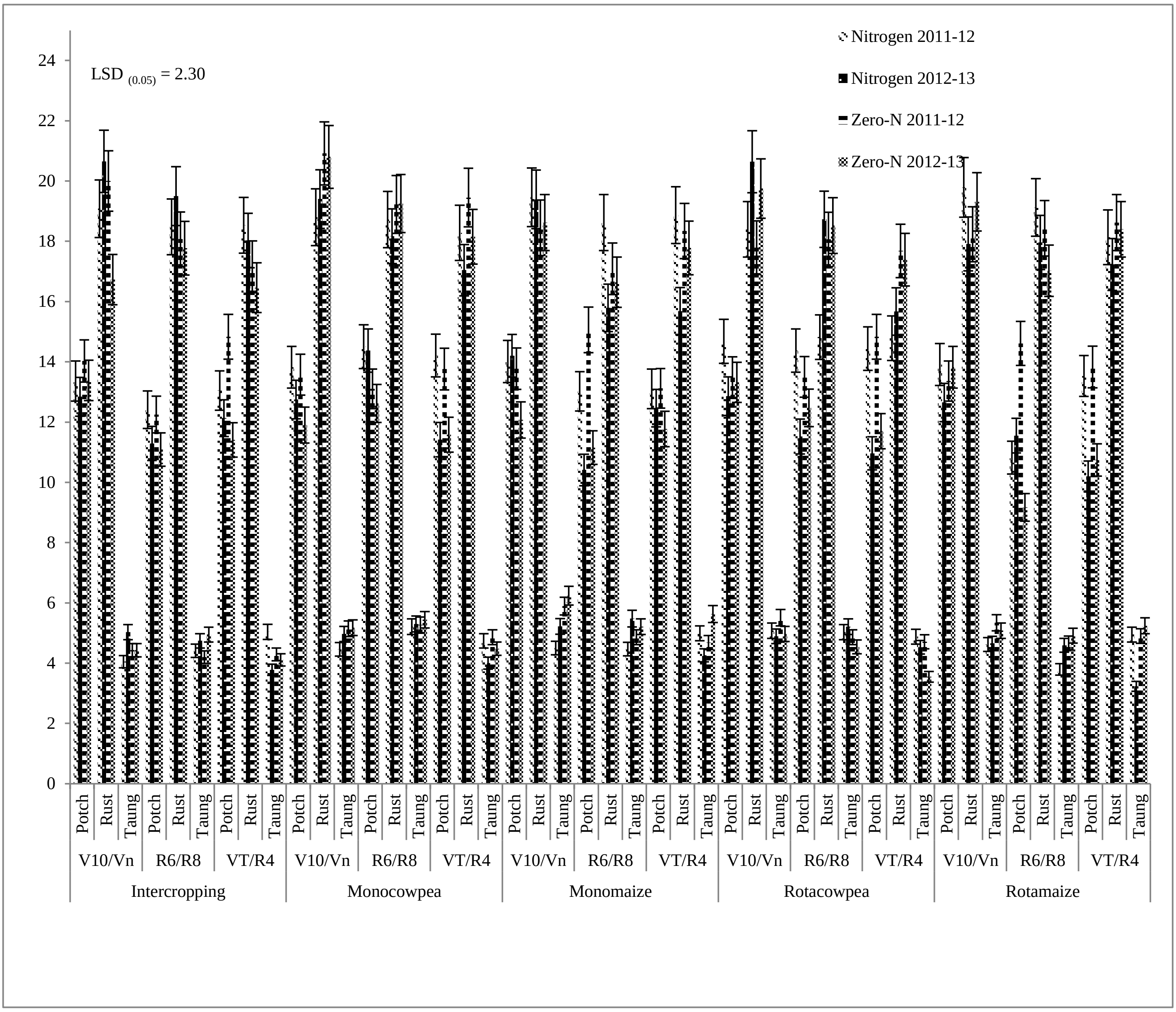


V10/V(n) = before tasseling of maize/ flowering of cowpea, R6/R8 = during physiological maturity of maize/cowpea, VT/R4 = during maize ear/cowpea pod formation, Rust = Rustenburg, Potch = Potchefstroom, Monocowpea = monocropping cowpea, Monomaize = monocropping maize, Rotacowpea = rotational cowpea, Rotamaize = rotational maize.

2.3.3. Soil moisture content at the depth of 30-60 cm

Cropping system had significant effect (P = 0.029) on soil moisture content at soil depth of 30-60 cm (Figure 2.3 and Appendix 2.1.C). Monocropping cowpea plots had significantly (P < 0.05) higher moisture content of 12.36% than other cropping systems. Growth stage had significant effect (P < 0.001) on soil moisture content. The growth stage before tasseling/flowering (V10/Vn) in maize/cowpea had significantly (P < 0.05) higher moisture content of 12.53% than VT/R4 and R6/R8 stages. Site also had significant effect (P < 0.001) on soil moisture content. Soil collected at Rustenburg and Potchefstroom had significantly (P < 0.001) higher moisture content of 18.26 and 12.84% respectively than soil collected at Taung. Season also showed significant effect (P < 0.001) on soil moisture content. The soil collected during 2011/12 planting season had significantly (P < 0.05) higher soil moisture content of 12.28% than soil collected at 2012/13 planting season. The interaction of cropping system x site (P = 0.011); growth stage x site (P = 0.004); and growth stage x season (P = 0.001) had significantly affected soil moisture content. The interaction of site x season (P < 0.001); cropping system x site x nitrogen (P = 0.008); and cropping system x site x season (P = 0.014) had also significantly affected soil moisture content.

Figure 2.3. The interaction of effects of cropping system, growth stage, site and N fertilization on soil moisture content in percentages at the depth of 30-60 cm.

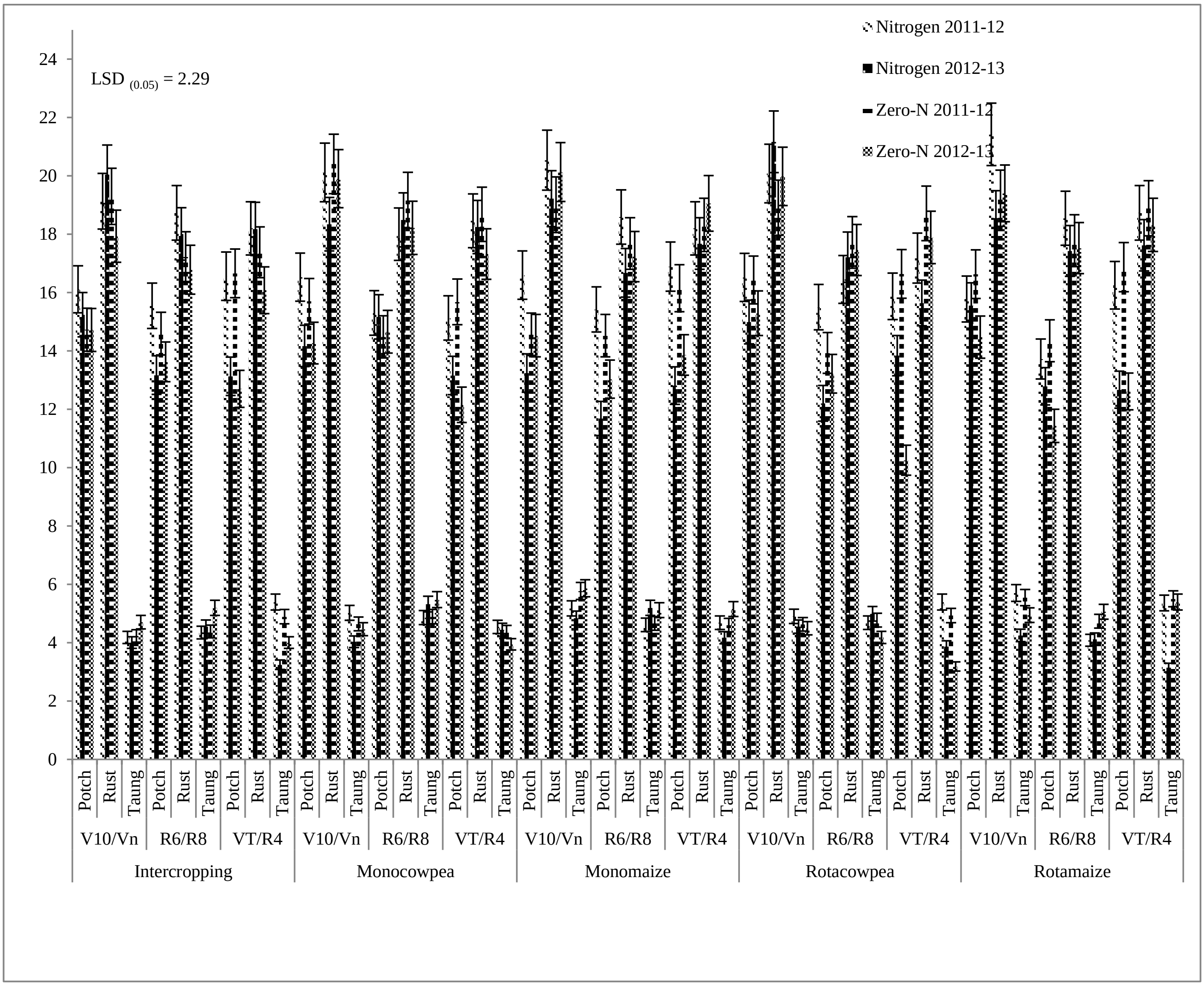


V10/V(n) = before tasseling of maize/ flowering of cowpea, R6/R8 = during physiological maturity of maize/cowpea, VT/R4 = during maize ear/cowpea pod formation, Rust = Rustenburg, Potch = Potchefstroom, Monocowpea = monocropping cowpea, Monomaize = monocropping maize, Rotacowpea = rotational cowpea, Rotamaize = rotational maize.

2.3.4. Soil moisture content at the depth of 60-90 cm

Growth stage had significant effect ($P < 0.001$) on soil moisture at the depth of 60-90 cm (Figure 2.4 and Appendix 2.1.D). The growth stage before tasseling/flowering (V10/Vn) in maize/cowpea had significantly ($P < 0.05$) higher moisture content of 13.25% than VT/R4 and R6/R8 stages. Site also had significant effect ($P < 0.001$) on soil moisture content. Soil collected at Rustenburg and Potchefstroom had significantly ($P < 0.05$) higher moisture content of 18.44 and 14.47% respectively than soil collected at Taung. Season also showed significant effect ($P < 0.001$) on soil moisture content. The soil collected during 2011/12 planting season had significantly ($P < 0.05$) higher soil moisture content of 13.07% than soil collected during 2012/13 planting season. The interaction of cropping system x growth stage ($P = 0.014$); growth stage x site; and growth stage x season ($P < 0.001$) had significantly affected on soil moisture content. The interaction of site x season ($P < 0.001$); and growth stage x site x season ($P = 0.034$) also had significantly affected soil moisture content.

Figure 2.4. The interaction of effects of cropping system, growth stage, site and N fertilization on soil moisture content in percentages at the depth of 60-90 cm.



V10/V(n) = before tasseling of maize/ flowering of cowpea, R6/R8 = during physiological maturity of maize/cowpea, VT/R4 = during maize ear/cowpea pod formation, Rust = Rustenburg, Potch = Potchefstroom, Monocowpea = monocropping cowpea, Monomaize = monocropping maize, Rotacowpea = rotational cowpea, Rotamaize = rotational maize.

2.4. Discussion

The times of soil sampling in this study, which were before tasseling/flowering, during pod/ear formation and physiological maturity of maize-cowpea played a significant role on soil moisture content. This corroborated the findings by Karuma *et al*. (2014) who reported the significant interaction between time x tillage x cropping system on soil moisture content. The higher soil moisture content at the depths of 0-15, 15-30, 30-60 and 60-90 cm before tasseling/flowering (V10/Vn) of maize-cowpea may have been attributed to high crop canopy cover during that stage. This implied that evaporation from soil surface was reduced and led to high availability of soil moisture at soil root zone. This confirmed the statements by Ghanbari *et al*. (2010) that water uptake from soil surface layers increased due to increased root density in the upper layers, thus decreasing water dissipated by evaporation. This corroborated the findings by Ghanbari *et al*. (2010) that water uptake from soil surface layers increased due to increased root density in the upper layers, thus decreasing water dissipated by evaporation. In this study, soil moisture was minimal during reproductive period (VT/R4) due to high uptake of soil water during that stage. It was then assumed that, critical soil moisture requirements and high water uptake by crops was during VT/R4 stage. During these stages, soil moisture content during analysis will be lower as compared to V10/Vn and R6/R8 stages. During V10/Vn and R6/R8 stages, it was always possible to find soil moisture in high quantity due to minimal usage by crops during those stages.

In this study, it was found that soil physical property played a significant role on soil moisture retention (Table 2.1). The higher moisture content in soil collected at Rustenburg and Potchefstroom may have been attributed to the clay percentage in the soil, which was able to hold moisture as compared to sandy soil at Taung. This corroborated the findings by Abdel-Nasser *et al*. (2007) that soil rich in clay content caused an increase in water holding capacity and reduction in evaporation. The higher soil moisture at Rustenburg and

Potchefstroom implied that site was also critical factor on soil moisture content. Dexter (2004) considered that, location with soil water retention ability could be used as indicator of soil physical quality. This implied that locality with poor soil structure will not be able to hold sufficient moisture to maintain good plant growth and this resulted with stunted plant growth due to reduction in absorption of plant nutrients. The higher moisture content in soil collected on cowpea plots planted on monocropping system may have been attributed to lower evaporation from sole cowpea plots. These findings corroborated the study of Steiner (2002) who reported that cropping systems that offer quick surface cover promote soil water content by reducing evaporation and increasing infiltration.

Ghanbari *et al*. (2010) found that soil moisture content in the soil was reduced dramatically in the sole crop of maize due to high evapotranspiration potential, on contrary soil moisture content in the soil was increased dramatically in the sole crop of cowpea due to low evapotranspiration potential for growth period. This implied that, canopy cover of dense cowpea cultivar played a significant role in soil moisture retention due to decreased evaporation rate from soil surface. It was expected for intercropping to play a role in soil moisture content based on the previous studies. Adiku *et al*. (1998) found that intercropping has the benefits to use water from different soil layers by the companion crops and enhances overall water use efficiency. In this study, intercropping had no significant role on soil moisture content. The type of cowpea cultivar plays a role on soil moisture content. It was assumed that, the cowpea cultivar (Bechuana white) which was indeterminate cultivar and covering large soil surface of the plots played a role in soil moisture content.

The interaction effects of growth stage x site x season on soil moisture content had significant contribution on moisture conservation, since such interactions was under 0-15, 15-30 and 60-90 cm depths. This implied that, soil moisture availability depends on the rate of evaporation during stages of crop growth and this was affected mainly by season and the type of location due to different soil types and climatic factors. Badel *et al*. (2013) found that, the effect of soil moisture depletion growth stages and their interaction effect on evapotranspiration at vegetative stage were highly significant. The growth stages which reduced evaporation because of canopy cover to the soil surface, the site with good soil physical properties with sufficient organic matter and season with good climatic factors were the main factors contributing significantly to high soil moisture retention. The interaction effects of season and site corroborated the findings by Shaw and Newman (2013) who reported that on hot sunny days with low humidity, evaporation demand on a crop is high, and thus a high amount of available soil moisture must be present if the crop is to avoid stress. In this study, the different in soil moisture across the sites and seasons was due to the fact that, under high humidity and cooler temperature, atmospheric evaporative demand was low, and this resulted in more soil moisture content.

2.5. Conclusions and recommendations

Monocropping plots of cowpea had the ability to hold soil moisture and this depends on the type of cowpea cultivar. The stage before tasseling/flowering of maize-cowpea (V10/Vn) was found to have high moisture content. The critical stage for high soil moisture content was at ear/pod formation stage (VT/R4) in this study. Crop rotation and nitrogen fertilization had no effect on soil moisture content. Soil physical properties affect soil moisture content. High soil moisture content was expected in soil with high organic matter content.

In this study, it was found that locations with high percentage of clay content (Potchefstroom and Rustenburg) were able to hold soil moisture content during different stages of sampling. Soil moisture content was site dependent. The indeterminate cowpea cultivar (Bechuana white) was the best cultivar to reduce evaporation on the soil surface. It is then recommended that, legumes should be included in cropping systems for the purpose of soil moisture conservation. The production of crops such as cereals and legumes in this study are recommended to be on the area with average clay percentage, since soil with average clay is able to hold moisture that will be available to crops.

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CHAPTER 3

CROP ROTATION AND INTERCROPPING COWPEA WITH MAIZE: MAIZE GROWTH AND YIELD

Abstract

Maize is the most important cereal crop in sub-Saharan Africa, high yielding and easy to process crop. A factorial experiment randomized in complete block design with three replications was conducted during 2011/12 and 2012/13 planting seasons. The experiment comprised of three cropping systems (cowpea-maize rotation, monocropping maize and intercropped maize), three sites (Potchefstroom, Taung and Rustenburg) and two rates of nitrogen fertilizers applied in kg ha^{-1} at each site (0 and 95 at Potchefstroom, 0 and 92 at Rustenburg, 0 and 113.5 at Taung). The experiment was conducted to investigate the effect of cropping system, site, and nitrogen fertilization on maize growth and yield. The measured growth and yield parameters were days to 100% tasseling, plant height, number of leaves per plant, leaf area, stem diameter, days to physiological maturity, ear length, ear mass, kernel number per ear, hundred seeds weight, grain yield, plant population, LER and stover yield. Cropping system ($P \leq 0.05$) had significant effect on maize growth, yield and yield components. Cowpea-maize rotation had significantly tasselled and reached physiological maturity earlier. Rotational maize had significantly ($P \leq 0.05$) large leaf area and taller plant than other cropping systems. Cowpea-maize rotation had significantly higher ear mass, kernel number per ear, grain yield and stover yield than maize planted on intercropping system. Maize planted at Potchefstroom had significantly large leaf area, higher number of leaves per plant, taller plants, large stem diameter longer ear length, higher ear mass, kernel number per ear, grain yield, plant population and stover yield than other sites. The application of nitrogen fertilizer under rotation contributes to higher yield of maize. Maize should be rotated with cowpea rather than be intercropped or monocropped.

Key words: Intercropping, monocropping, nitrogen, rotation, season.

3.1. Introduction

Maize is often grown in loose rotation with legumes, but most maize grown on the same land year after year as sole crops or intercropped with legumes. Maize plant reaches its maximum plant height soon after tasseling occurs. At tasseling, less than half of the final weight of the maize plant has been produced (Gurung *et al*., 2011). According to Rehman (2010) plant height is an important yield component. Intercropping significantly increases plant height in maize (Okpara, 2000). Plant height and leaf area index of maize crop in maize and legume intercropping system are better in intercropping system compared to sole maize (Rana *et al*., 2001). Leaf area is influenced by plant population and soil fertility (Okpara, 2000). It was further indicated that the presence of nitrogen helps in developing leaf area and lateral stem as a result of the increase in the physiological growth indices. Plant height and leaf area per plant are also influenced by the previous legume (Adeleke and Haruna, 2012). According to Widowati *et al*. (2012) nitrogen application improves plant growth by increasing plant height and stem diameter at the end of vegetative growth. It was further indicated that since nitrogen promoted growth, it enhances leaf expansion and development. This influence may result in an increase in leaf length and width and leaf blade size (Eltelib *et al*., 2006). This confirmed the fact that nitrogen was the most essential element needed for plant growth and development. It was further indicated that continuous intercropping of maize on the same strip in the early and late cropping seasons results with very poor growth of maize.

Maize yield depends on many factors such as fertilizer application, soil types and cropping systems. Cereal-cowpea in rotation improved cereal grain by 18 and 25% respectively, on the loam averaged across tillage regimes and years (Kouyate *et al*., 1999). Continuous corn has responded up to the highest N rates used (Higgs *et al*., 1976). In monoculture corn, the high rate of N fertilizer was required to achieve normalized yield levels similar to normalized yields obtained in any of the two or four years cropping systems without any N fertilizer or monoculture soybean at any level (Stanger and Lauer, 2008). Crop rotation involving grain legumes was a viable management option that helped increase maize yield and can substitute the unproductive fallow system traditionally used for soil fertility maintenance (Iwuafor *et al*., 2006). To attain highest productivity level, therefore, it was necessary to combine rotational systems with mineral N fertilization. It was reported that, two year rotation was not sufficient to improve corn grain yield, whereas the five year rotation was able to enhance corn grain yield and decreases the need for fertilizer N (Stanger and Lauer, 2008). Soil infertility was the most critical factor limiting maize grain yield over most regions (Zou *et al*., 2008). N fertilizer was accepted as a key input to high corn grain yield and optimum economic return (Oberle and Keeney, 1990). N application that meet, but not exceed, N requirement for maximum corn yield were essential to minimizing environmental risks associated with N fertilizer application (Gehl *et al*., 2005). The relationship between maize grain yield and management practices varied overtime and space depending on the maize cultivars, climatic conditions and cropping systems (Yin *et al*., 2014). Studies showed that mixtures of cereals and legumes produce higher grain yields than either crop grown alone (Olufemi *et al*., 2001). The yield increase was not only due to improved N nutrition of cereal component, but also to other unknown causes (Connolly *et al*., 2001). Maize grain yield was highly variable across years with or without fertilizer and was reduced in years of low and high rainfall (Waddington *et al*., 2007).

In most of the previous studies, intercropping and rotational cropping were studied separately. The hypothesis is that, monocropping system will not have higher yield as compared to other cropping system. The main effort was geared towards studying the interaction effects of site, cropping system, nitrogen fertilization and season on maize yield. The objective of this study was to determine the effect of cropping system, site and N fertilization on maize yield.

3.2. Materials and methods

3.2.1. Experimental sites

The study was conducted at three dryland sites in South Africa, namely the department of Agriculture experimental station in Taung situated at 27^0 30′S and 24^0 30′E, Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^0 26′S and 27^0 26′E and the Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg 25^0 43′S and 27^0 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*., 1968).

3.2.2. Experimental design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in random complete block design (RCBD) with three replicates. The experiment consisted of three cropping systems (monocropping, rotational and intercropping), three sites Potchefstroom, Taung and Rustenburg and two levels of N fertilizer at each site, which were the amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1}

applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

3.2.3. Data collection and agronomic practices

Days to 100 % tasseling were recorded during each planting season. Maize plant height and stem diameter were recorded from three selected plants from harvest area of 12 m^2 of each maize plot during maturity stage. Number of leaves per plant was also recorded from three selected plants and averaged. Leaf area per plant was measured by length (L) and width (W) corrected to 0.75, as described by Saxena and Singth (1965).

LA = 0.75 (L x W) Where: L = leaf length, cm

W = width of widest portion of leaf, cm

LA = leaf area, cm^2

Grain yield was recorded from the harvest area of 12 m^2 within each plot of rotational, monocropping and intercropping systems. Maize ears were collected from the sampling/harvest area and ear mass and ear population per hectare were recorded. Ear length was recorded from four randomly harvested ears collected from harvested area and averaged. Ears were thrashed and weight to determine grain yield per plot. Hundred seeds mass per plot was also determined. Grain yield and 100 seed weight mass were converted to kg/ha. Plant population was recorded by counting number of plants per harvested area in each plot.

$$\text{LER} = \frac{\text{Cowpea intercrop yield}}{\text{Cowpea sole yield}} + \frac{\text{Corn intercrop yield}}{\text{Corn sole crop yield}}$$

When LER ≤ 1, intercropping is disadvantageous while LER ≥ 1, implies intercropping is advantageous (Benites *et al*., 1993).

Stover yield was calculated by taking subsample fresh weight and divide it by oven dry sample and multiply it by field biomass weight.

$$\text{Stover yield} = \frac{\text{Subsample fresh weight}}{\text{Oven dry subsample}} \text{ x Field biomass weight}$$

Analysis of variance was performed using GenStat 14th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered as significant statistically (Gomez and Gomez, 1984).

Table 3.1. The mean temperature and rainfall data for Potchefstroom, Taung and Rustenburg for the duration of experimental period.

Site	**Season**	**Climate data**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Potch	2011/12	Rainfall(mm)	35.58	66.29	75.95	19.05	33.78	66.29	4.32	0
		Max T (˚C)	28.64	29.45	28.57	30.42	29.11	28.72	25.00	25.00
		Min T (˚C)	11.19	13.78	15.81	16.22	16.30	13.59	8.05	5.17
	2012/13	Rainfall(mm)	21.84	13.46	42.42	45.72	28.7	43.94	47.5	8.14
		Max T (˚C)	29.01	30.21	27.99	30.11	31.03	28.43	24.32	22.61
		Min T (˚C)	12.43	14.62	15.41	16.81	15.5	14.58	9.12	3.86
Taung	2011/12	Rainfall(mm)	3.05	36.07	71.37	7.87	40.89	12.45	5.08	0.51
		Max T (˚C)	31.05	33.28	32.8	36.12	32.87	32.96	28.02	27.65
		Min T (˚C)	9.25	10.6	14.79	16.19	17.01	13.75	8.24	4.48
	2012/13	Rainfall(mm)	0.25	8.89	14.99	40.89	32.00	14.2	9.2	8.4
		Max T (˚C)	32.5	34.98	32.86	36.29	31.5	31.8	27.3	26.8
		Min T (˚C)	10.74	14.27	15.71	17.83	17.7	15	9.4	6.2
Rust	2011/12	Rainfall(mm)	23.37	49.79	47.24	19.3	6.35	27.94	6.6	0.25
		Max T (˚C)	28.68	30.18	28.28	30.20	30.95	29.00	25.04	25.13
		Min T (˚C)	11.71	14.91	17.00	15.34	17.21	14.37	9.34	6.58
	2012/13	Rainfall(mm)	21.08	25.91	48.01	37.34	20.58	10.92	46.48	0
		Max T (˚C)	28.28	29.95	28.13	29.9	31.05	29.05	25.48	23.23
		Min T (˚C)	12.82	14.76	16.14	17.38	16.28	14.67	10.17	4.68

3.3. Results

3.3.1. Days to 100% tasseling of maize

Cropping system had significant effect ($P = 0.005$) on days to 100% tasseling of maize (Table 3.2 and Appendix 3.1.A). Cowpea-maize rotation had significantly ($P < 0.05$) tasselled earlier at 72.1 days than intercropped and monocropped maize. Days to 100% tasseling of maize were significantly affected ($P \leq 0.001$) by site effect. Maize planted at Rustenburg and Potchefstroom had significantly ($P < 0.05$) tasselled earlier at 67.2 and 73.7 days respectively than maize planted at Taung. N fertilizer application had significant effect ($P \leq 0.001$) on days to 100% tasseling of maize. Maize applied with N fertilizer had tasselled significantly ($P < 0.05$) earlier at 70.1 days than maize without N fertilizer application. Maize planted during 2012/13 planting season tasselled significantly ($P < 0.05$) earlier at 71.6 days than maize planted during 2011/12 planting season. Days to 100% tasseling of maize were significantly affected ($P \leq 0.001$) by the interaction of site x nitrogen; and site x season.

Table 3.2. The interaction effects of cropping system, site and N fertilizer on days to 100% tasseling of maize.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	80.00 c	69.33 ghij	82.00 bc	69.00 ghij
	Rust	62.67 kl	65.00 ikl	73.00 defgh	70.33 fghi
	Taung	75.67 cdf	73.33 defg	88.00 a	87.33 ab
Monocropped	Potch	76.00 cde	69.00 ghij	80.00 c	72.67 defgh
	Rust	62.00 l	64.00 jkl	72.67 defgh	70.33 fghi
	Taung	76.00 cde	73.33 defg	88.00 a	85.67 ab
Rotational	Potch	74.00 defg	67.67 hijk	74.33 defg	70.67 efgh
	Rust	62.33 kl	62.67 kl	73.67 defg	67.67 hijk
	Taung	75.00 cdef	73.00 defgh	86.67 ab	78.00 cd
SEM	1.92				
LSD $_{(0.05)}$	5.42				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.2. Days to physiological maturity

Cropping system had significant effect ($P \leq 0.001$) on days to physiological maturity of maize (Table 3.3 and Appendix 3.1.B). Monocropped maize and cowpea-maize rotation had significantly ($P < 0.05$) reached days to physiological maturity earlier at 157.0 and 155.9 days respectively than intercropped maize. Days to physiological maturity were significantly affected ($P \leq 0.001$) by the site effect. Maize planted at Taung and Rustenburg had significantly ($P < 0.05$) reached days to physiological maturity earlier at 133.4 and 155.6 days respectively than maize planted at Potchefstroom. N fertilizer application had significant effect ($P \leq 0.001$) on days to physiological maturity. Maize applied with N fertilizer had significantly ($P < 0.05$) reached days to physiological maturity earlier at 155.7 days than maize without N fertilizer application. Maize planted during 2012/13 planting season had significantly ($P < 0.05$) reached days to physiological maturity earlier at 150.9 days than 2011/12 planting season.

Days to physiological maturity of maize was significantly affected by the interaction of cropping system x site, cropping system x nitrogen ($P = 0.03$), site x nitrogen. The interaction of site x season; cropping system x nitrogen x season ($P \leq 0.001$) and site x nitrogen x season ($P = 0.001$) had significant effect of days to physiological maturity. The interaction of cropping system x site x nitrogen x season ($P = 0.04$) also had significant effect on days to physiological maturity.

Table 3.3. The interaction effects of cropping system, site and N fertilizer on days to physiological maturity of maize.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	191.00 a	188.00 ab	184.33 cd	176.00 f
	Rust	160.00i	142.67 mn	167.00 h	152.67 kl
	Taung	141.00 n	121.00 r	143.67 mn	132.33 p
Monocropped	Potch	187.00 bc	181.00 e	182.33 de	174.00 fg
	Rust	159.67 i	143.33 mn	166.67 h	155.00 jk
	Taung	136.00 o	122.67 qr	145.67 m	131.00 p
Rotational	Potch	186.00 bc	184.33 cd	181.00 e	171.33 g
	Rust	158.00 ij	144.00 mn	168.00 h	150.00 l
	Taung	136.00 o	121.33 r	145.00 m	125.67 q
SEM	1.15				
LSD $_{(0.05)}$	3.24				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.3. Maize leaf area

Cropping system had significant effect ($P = 0.02$) on maize leaf area (Table 3.4 and Appendix 3.1.C). Cowpea-maize rotation had significantly ($P < 0.05$) large leaf area of 724.7 cm^2 than intercropping and monocropping maize. Maize leaf area was significantly affected ($P < 0.001$) by the effect of site. Maize planted at Potchefstroom had significantly ($P < 0.05$) large leaf area of 896.2 cm^2 than maize planted at Rustenburg and Taung. N fertilizer application had significant effect ($P < 0.001$) on maize leaf area. Maize applied with N fertilizer had significantly ($P < 0.05$) large leaf area of 796.1 cm^2 than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) large leaf area of 735.9 cm^2 than maize planted during 2012/13 planting season. Maize leaf area was significantly affected by the interaction of cropping system x season ($P = 002$) and cropping system x site x nitrogen ($P = 0.032$).

Table 3.4. The interaction effects of cropping system, site and N fertilizer on maize leaf area in cm^2.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	1041.8 ab	888.4 bc	776.0 cde	586.9 fghij
	Rust	715.5 defgh	569.9 ghijk	513.3 ijkl	323.0 n
	Taung	738.0 cdef	527.1 ijkl	713.9 defgh	329.3 n
Monocropped	Potch	1053.0 a	1054.3 a	730.5 def	766.7 cde
	Rust	638.0 efghi	602.6 fghij	600.1 fghij	351.9 mn
	Taung	782.9 cde	713.7 defgh	380.3 lmn	340.2 mn
Rotational	Potch	1152.9 a	1042.2 ab	856.0 cd	805.5 cd
	Rust	720.6 defg	597.3 fghij	494.3 ijklm	448.3 jklmn
	Taung	776.2 cde	714.4 defgh	563.3 hijk	425.8 klmn
SEM	55.69				
LSD $_{(0.05)}$	157.07				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.4. Number of leaves per maize plant

Number of leaves per maize plant was significantly affected ($P \leq 0.001$) by the effect of site (Table 3.5 and Appendix 3.1.D). Maize planted at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher number of leaves per plant of 15.1 and 12.8 respectively than maize planted at Taung. Number of leaves per maize plant was significantly affected by the interaction of site x nitrogen ($P = 0.03$) and site x season ($P \leq 0.001$).

Table 3.5. The interaction effects of cropping system, site and N fertilizer on number of leaves per maize plant.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	14.1 abcdefgh	15.2 abc	15.8 a	14.3 abcdefgh
	Rust	15.2 abc	13.7 bcdefghi	14.9 abcdef	13.2 efghi
	Taung	13.0 ghi	13.6 bcdefghi	10.8 k	12.0 ijk
Monocropped	Potch	14.0 abcdefgh	15.0 abcde	15.7 a	15.4 ab
	Rust	15.3 abc	13.7 bcdefghi	15.2 abc	13.0 ghi
	Taung	12.8 hij	13.0 ghi	11.1 jk	12.6 hijk
Rotational	Potch	15.4 ab	15.1 abcd	15.1 abcd	15.6 a
	Rust	15.0 abcde	13.5 cdefghi	15.6 a	13.1 fghi
	Taung	13.3 defghi	14.4 abcdefgh	12.0 ijk	14.7 abcdefg
SEM	0.69				
LSD $_{(0.05)}$	1.94				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.5. Maize plant height

Cropping system had significant effect ($P < 0.001$) on maize plant height (Table 3.6 and Appendix 3.1.E). Cowpea-maize rotation and monocropping maize had significantly ($P < 0.05$) taller plant height of 191.6 and 182.6 cm respectively than intercropping maize. Maize plant height was significantly affected ($P < 0.001$) by the effect of site. Maize planted at Potchefstroom and Rustenburg had significantly ($P < 0.05$) taller plant height of 199.7 and 187.4 cm respectively than maize planted at Taung. N fertilizer application also had significant effect ($P < 0.001$) on maize plant height. Maize applied with N fertilizer had significantly ($P < 0.05$) taller plant of 191.7 cm than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) taller maize plant of 196.3 cm than maize planted during 2012/13 planting season. Maize plant height was significantly affected by the interaction of site x season ($P < 0.001$) and nitrogen x season ($P = 0.04$).

Table 3.6. The interaction effects of cropping system, site and N fertilizer on maize plant height in centimetres.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	218.5 abc	163.9 ijklm	213.1 abcd	139.8 lmn
	Rust	192.8 cdefgh	198.7 cdef	173.8 fghijk	159.9 ijklm
	Taung	170.7 fghijk	136.3 mn	176.1 efghijk	126.5 n
Monocropped	Potch	238.8 ab	195.6 cdefg	211.3 bcd	164.4 hijklm
	Rust	195.2 cdefg	203.1 cde	187.5 defghi	169.6 ghijk
	Taung	179.9 efghij	167.0 ghijkl	150.0 klmn	129.1 n
Rotational	Potch	241.3 a	195.6 cdefg	238.0 ab	175.6 efghijk
	Rust	203.3 cde	203.9 cde	182.4 efghi	178.3 efghijk
	Taung	178.6 efghijk	168.0 ghijkl	181.9 efghi	152.4 jklmn
SEM	10.21				
LSD $_{(0.05)}$	28.79				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.6. Maize stem diameter

Maize stem diameter was significantly affected ($P < 0.001$) by site effect (Table 3.7 and Appendix 3.1.F). Maize planted at Potchefstroom had significantly ($P < 0.05$) large stem diameter of 2.0 cm than maize planted at Taung and Rustenburg. N fertilizer application had significant effect ($P < 0.001$) on maize stem diameter. Maize applied with N fertilizer had significantly ($P < 0.05$) large stem diameter of 2.0 cm than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) large stem diameter of 1.9 cm than maize planted during 2012/13 planting season. Maize stem diameter was significantly affected by the interaction of site x nitrogen ($P < 0.001$) and cropping system x season ($P = 0.02$).

Table 3.7. The interaction effects of cropping system, site and N fertilizer on maize stem diameter in centimetres.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	2.5 a	2.2 abcd	1.7 fghi	1.3 jkl
	Rust	1.8 efgh	1.5 hijk	1.5 hijk	1.1 l
	Taung	2.1 bcde	1.6 ghij	2.0 cdef	1.3 jkl
Monocropped	Potch	2.4 ab	2.3 abc	1.6 ghij	1.7 fghi
	Rust	1.8 efgh	1.5 hijk	1.6 ghij	1.2 kl
	Taung	2.2 abcd	2.0 cdef	1.5 hijk	1.3 jkl
Rotational	Potch	2.5 a	2.3 abc	1.9 defg	1.8 efgh
	Rust	1.8 efgh	1.5 hijk	1.4 ijkl	1.3 jkl
	Taung	2.1 bcde	2.0 cdef	1.8 efgh	1.5 hijk
SEM	0.13				
LSD $_{(0.05)}$	0.4				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.7. Maize ear length

Cropping system had significant effect ($P = 0.049$) on maize ear length (Table 3.8 and Appendix 3.1.G). Cowpea-maize in rotational cropping had significantly ($P < 0.05$) longer ear length of 15.5 cm than intercropped and monocropped maize. Maize ear length was significantly affected ($P < 0.001$) by the effect of site. Maize planted at Potchefstroom and Taung had significantly ($P < 0.05$) longer ear length of 16.0 and 14.9 cm respectively than maize planted at Rustenburg. N fertilizer application also had significant effect ($P < 0.001$) on maize ear length. Maize applied with N fertilizer had significantly ($P < 0.05$) longer ear length of 16.2 cm than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) longer ear length of 15.4 cm than maize planted during 2012/13 planting season. Maize ear length was significantly affected ($P = 0.017$) by the interaction effect of site x season.

Table 3.8. The interaction effects of cropping system, site and N fertilizer on maize ear length in centimetres.

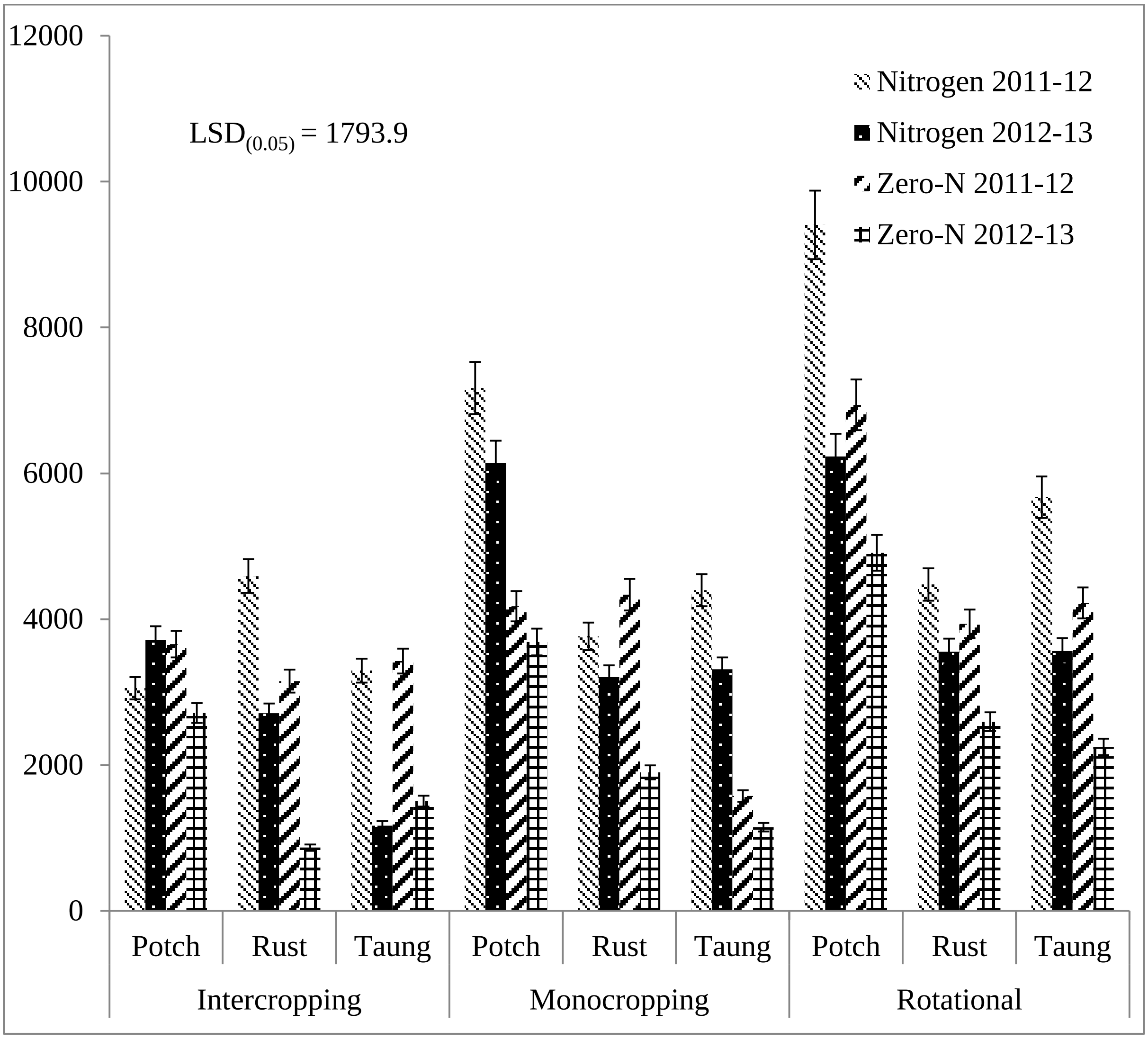
		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	20.2 a	17.2 bcd	13.1 ijklm	12.8 jklm
	Rust	15.6 bcdefghi	14.1 efghijklm	13.5 hijklm	9.9 n
	Taung	15.9 bcdefgh	15.6 bcdefghi	15.9 bcdefgh	13.6 ghijklm
Monocropped	Potch	16.8 bcd	17.1 bcd	14.8 defghijkl	14.8 defghijkl
	Rust	16.3 bcdefg	14.3 efghijkl	12.3 klmn	12.2 lmn
	Taung	13.9 ghijklm	16.1 bcdefgh	12.8 jklm	12.9 ijklm
Rotational	Potch	17.6 abc	16.8 bcd	15.3 bcdefghij	16.0 bcdefgh
	Rust	15.5 bcdefghij	15.0 cdefghijk	16.7 bcdef	11.5 mn
	Taung	15.1 bcdefghij	17.8 ab	15.0 cdefghijk	14.0 fghijklm
SEM	1.02				
LSD $_{(0.05)}$	2.8				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.8. Maize ear mass

Cropping system had significant effect ($P < 0.001$) on maize ear mass (Figure 3.1 and Appendix 3.1.H). Monocropped maize and cowpea-maize in rotational cropping had significantly ($P < 0.05$) higher ear mass of 3734.0 and 4812.3 kg ha^{-1} respectively than intercropped maize. Maize ear mass was significantly affected ($P < 0.001$) by the effect of site. Maize planted at Potchefstroom had significantly ($P < 0.05$) higher ear mass of 5149.8 kg ha^{-1} than maize planted at Rustenburg and Taung. N fertilizer application also had significant effect ($P < 0.001$) on maize ear mass. Maize applied with N fertilizer had significantly ($P < 0.05$) higher ear mass of 4412.2 kg ha^{-1} than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) higher ear mass of 4513.4 kg ha^{-1} than maize planted during 2012/13 planting season. Maize ear mass was significantly affected by the interaction effect of cropping system x site ($P < 0.001$); cropping system x nitrogen ($P = 0.043$); and cropping system x site x nitrogen ($P = 0.017$).

Figure 3.1. The interaction effects of cropping system, site and N fertilizer on maize ear mass in kg ha^{-1}.



3.3.9. Maize kernel number per ear

Cropping system had significant effect ($P = 0.016$) on maize kernel number per ear (Table 3.9 and Appendix 3.1.I). Monocropped maize and cowpea-maize in rotational cropping had significantly ($P < 0.05$) higher kernel number of 393.8 and 413.4 respectively than intercropped maize. Maize kernel number per ear was significantly affected ($P < 0.001$) by site effect. Maize planted at Potchefstroom had significantly ($P < 0.05$) higher kernel number of 433.9 than maize planted at Rustenburg and Taung. N fertilizer application also had significant effect ($P < 0.001$) on maize kernel number per ear. Maize applied with N fertilizer had significantly ($P < 0.05$) higher kernel number of 432.9 than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) higher kernel number per ear of 405.5 than maize planted during 2012/13 planting season. Maize kernel number per ear was significantly affected ($P = 0.034$) by the interaction effect of site x season.

Table 3.9. The interaction effects of cropping system, site and N fertilizer on maize kernel number per ear.

		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	529.5 ab	396.8 efghij	357.7 ghijkl	293.3 jkl
	Rust	418.0 bcdefgh	351.5 ghijkl	301.6 ijkl	246.6 l
	Taung	380.3 fghijk	357.2 ghijkl	391.5 efghijk	356.5 ghijkl
Monocropped	Potch	537.3 a	489.3 abcdef	418.3 bcdefgh	381.7 fghijk
	Rust	404.3 defghij	387.5 efghijk	356.2 ghijkl	307.3 hijklm
	Taung	401.4 defghij	426.1 abcdefg	310.0 hijkl	307.0 hijklm
Rotational	Potch	499.1 abcde	510.0 abcd	409.8 defghi	384.2 fghijk
	Rust	433.3 abcdefg	395.6 efghij	414.2 cdefghi	280.4 kl
	Taung	351.0 ghijkl	523.9 abc	386.4 efghijk	372.6 ghijk
SEM	40.13				
LSD $_{(0.05)}$	113.20				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.10. Maize hundred seed mass

Maize hundred seed mass was significantly affected ($P = 0.007$) by site effect (Table 3.10 and Appendix 3.1.J). Maize planted at Taung had significantly ($P < 0.05$) higher seed mass of 25.3 kg ha^{-1} than maize planted at Potchefstroom and Rustenburg. N fertilizer application had significant effect ($P < 0.001$) on maize seed mass. Maize applied with N fertilizer had significantly ($P < 0.05$) higher seed mass of 25.7 kg ha^{-1} than maize without N fertilizer application. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) higher seed mass of 27.1 than maize planted during 2012/13 planting season. Maize hundred seed mass was significantly affected ($P < 0.001$) by interaction effect of site x nitrogen and site x season.

Table 3.10. The interaction effects of cropping system, site and N fertilizer on hundred seed mass in kg ha^{-1}.

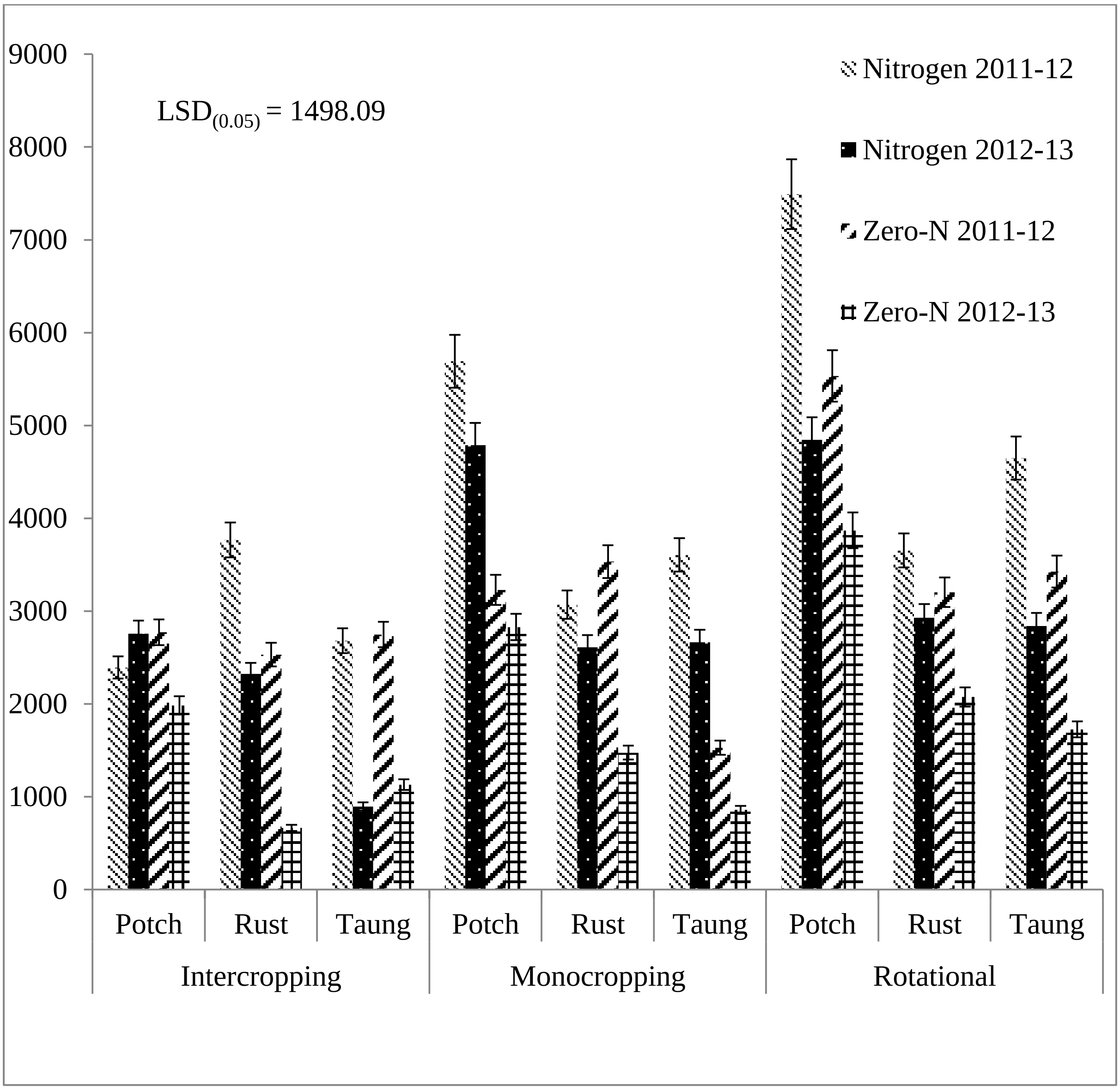
		N-fertilization		**Zero-N**	
Cropping system	Site	2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	26.1 defghij	23.6 klmn	24.7 ghijk	24.2 ijkl
	Rust	28.9 abc	19.2 q	26.7 cdefgh	20.8 opq
	Taung	29.7 a	24.7 ghijk	27.5 abcde	21.1 opq
Monocropped	Potch	26.9 cdefg	23.6 klmn	22.2 lmno	22.2 lmno
	Rust	28.3 abcd	20.0 pq	27.5 abcde	21.4 nopq
	Taung	29.5 ab	25.0 fghijk	24.4 hijkl	19.5 pg
Rotational	Potch	28.7 abc	25.3 efghijk	24.4 hijkl	22.2 lmno
	Rust	28.6 abc	20.6 opq	26.6 cdefghi	21.1 opq
	Taung	29.5 ab	23.9 jklm	27.2 bcdef	21.7 mnop
SEM	0.90				
LSD $_{(0.05)}$	2.5				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

3.3.11. Maize grain yield

Cropping system had significant effect ($P < 0.001$) on maize grain yield (Figure 3.2 and Appendix 3.1.K). Monocropped maize and cowpea-maize in rotational cropping had significantly ($P < 0.05$) higher grain yield of 2990.0 and 3853.0 kg ha^{-1} than intercropped maize. Maize grain yield was significantly affected ($P < 0.001$) by site effect. Maize planted at Potchefstroom had significantly ($P < 0.05$) higher grain yield of 4015.1 kg ha^{-1} than maize planted at Rustenburg and Taung. N fertilizer application had significant effect ($P < 0.001$) on maize grain yield. Maize applied with N fertilizer had significantly ($P < 0.05$) higher grain yield of 3536.3 kg ha^{-1} than maize without N fertilizer. Maize planted during 2011/12 planting season had significantly ($P < 0.05$) higher grain yield of 3638.9 kg ha^{-1} than maize planted during 2012/13 planting season. Maize grain yield was significantly affected by the interaction effect of cropping system x site ($P < 0.001$) and the interaction of cropping system x site x nitrogen ($P = 0.022$).

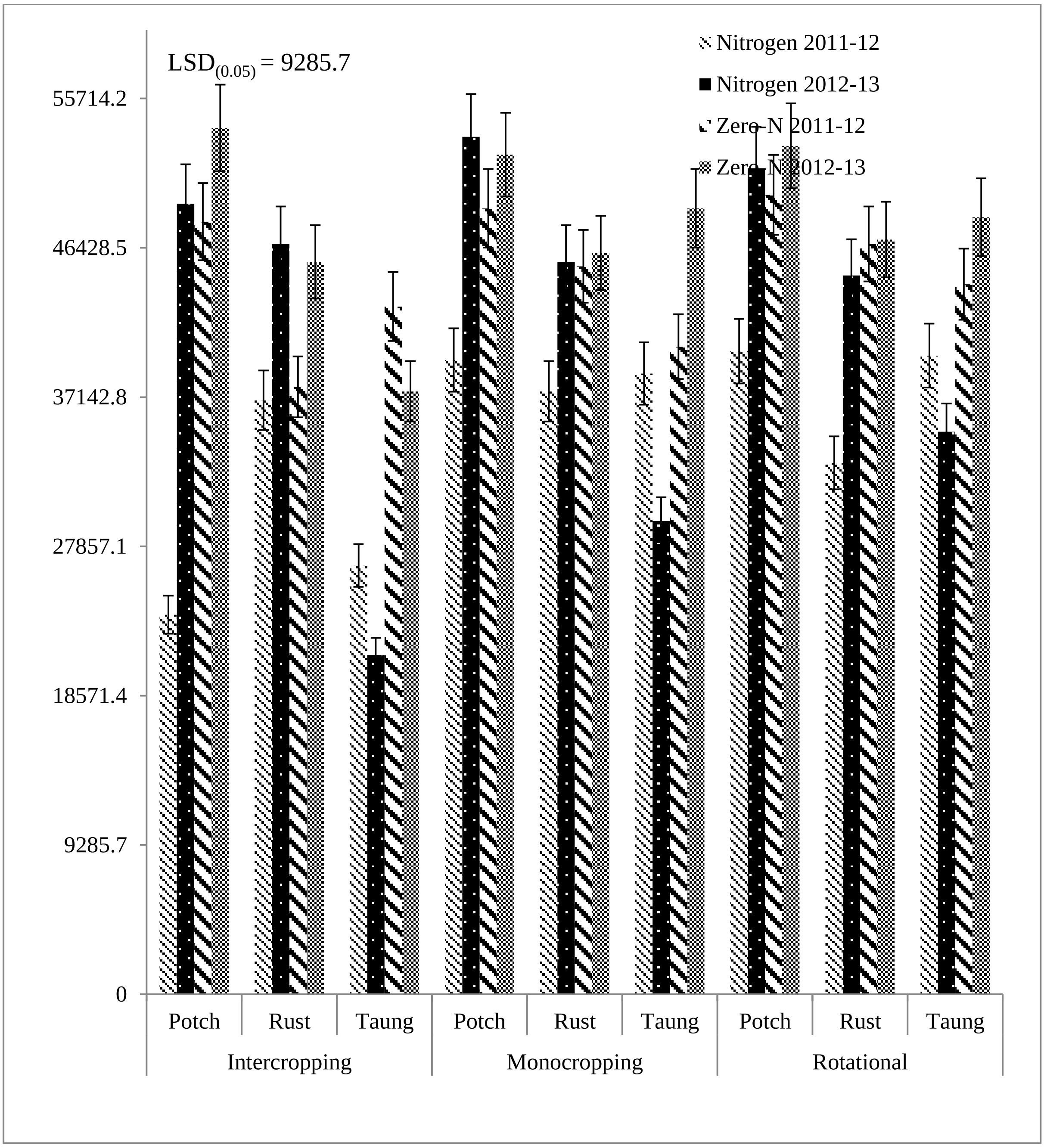
Figure 3.2. The interaction effects of cropping system, site and N fertilizer on maize grain yield in kg ha^{-1}.



3.3.12. Maize plant population at harvest

Cropping system had significant effect ($P \leq 0.001$) on maize plant population (Figure 3.3 and Appendix 3.1.L). Monocropped maize and cowpea-maize rotation had significantly ($P < 0.05$) higher plant population of 43796.3 and 44375.0 ha^{-1} respectively than maize planted on intercropping system. Maize plant population at harvest was significantly affected ($P \leq 0.001$) by the site effect. Maize planted at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher plant population of 46875.0 and 42731.5 ha^{-1} respectively than maize planted at Taung. N fertilizer application had significantly affected ($P \leq 0.001$) maize plant population at harvest. Maize without N fertilizer application had significantly ($P < 0.05$) higher plant population of 46435.2 ha^{-1} than maize applied with N fertilizer. Maize planted during 2012/13 planting season had significantly ($P < 0.05$) higher plant population of 44922.8 ha^{-1} than maize planted during 2011/12 planting season. Maize plant population was significantly affected by the interaction of site x nitrogen ($P = 0.017$); the interaction of site x season; and the interaction of site x nitrogen x season ($P \leq 0.001$).

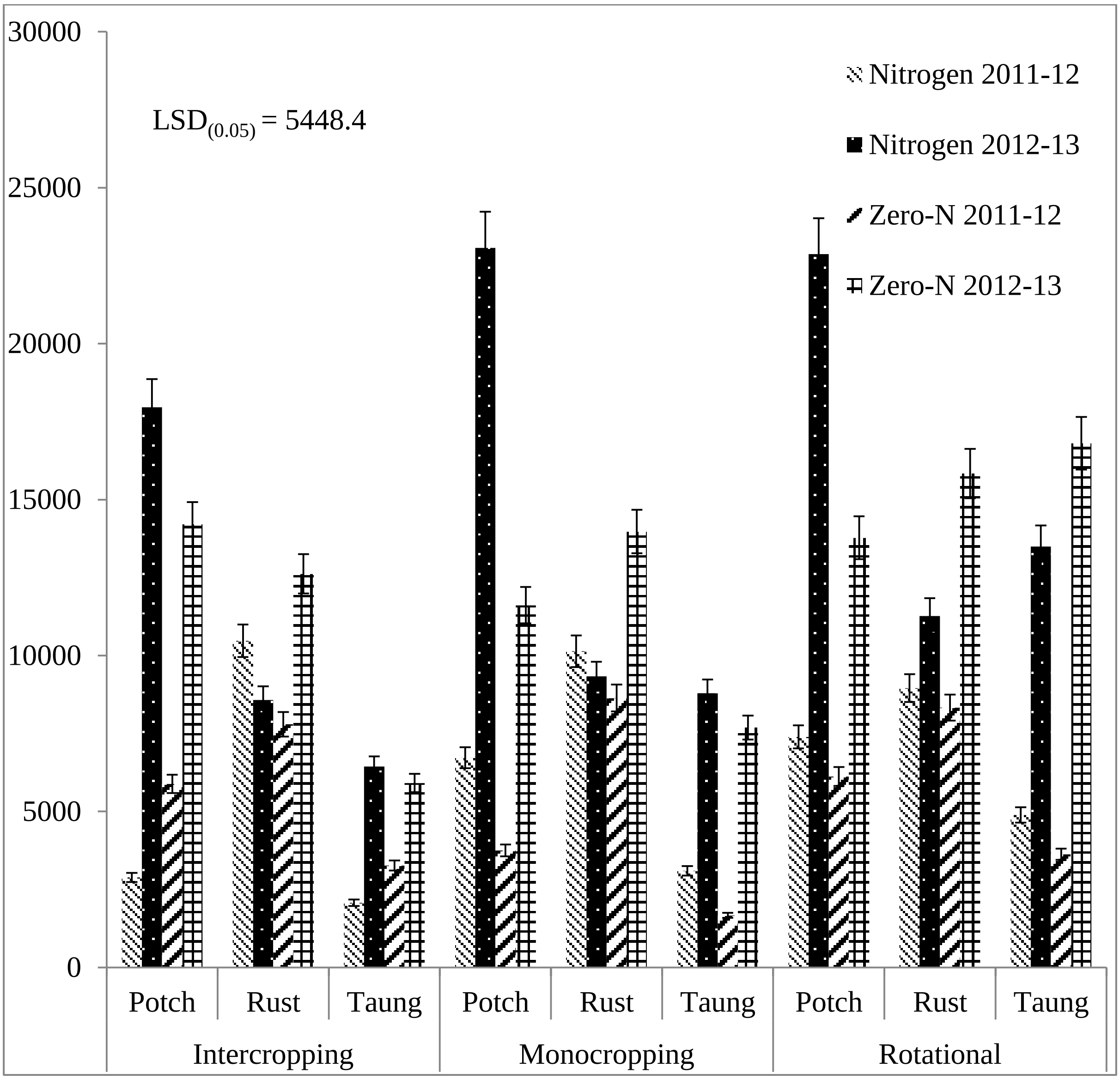
Figure 3.3. The interaction effects of cropping system, site and N fertilizer on maize plant population per hectare.



3.3.13. Maize stover yield

Cropping system had significant effect ($P = 0.001$) on maize stover yield (Figure 3.4 and Appendix 3.1.M). Cowpea-maize rotation had significantly ($P < 0.05$) higher stover yield of 11115.2 kg ha^{-1} than intercropped and monocropped maize. Maize stover yield was significantly affected ($P < 0.001$) by site effect. Maize planted at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher stover yield of 11356.6 and 10496.7 kg ha^{-1} respectively than maize planted at Taung. Maize planted during 2012/13 planting season had significantly ($P < 0.05$) higher stover yield of 13016.4 kg ha^{-1} than maize planted during 2011/12 planting season. Maize stover yield was significantly affected by the interaction of site x nitrogen ($P = 0.002$); the interaction of site x season; and the interaction of site x nitrogen x season ($P < 0.001$).

Figure 3.4. The interaction effects of cropping system, site and N fertilizer on maize stover yield in kg ha^{-1}.



3.3.14. Land equivalent ratio of maize-cowpea under nitrogen and zero N fertilizer application

The calculated values of land equivalent ratio (LER) for individual crop as well as total LER under different sites and seasons are presented in Table 3.11. At Potchefstroom, the partial LER maize under maize-cowpea intercropping with N fertilization was increased during 2012/13 than in 2011/12 planting season. The partial LER for maize under maize-cowpea intercropping with zero N fertilizer was increased during 2011/12 than in 2012/13 planting season. The partial LER for cowpea under maize-cowpea intercropping with N fertilization and zero N fertilization was increased during 2011/12 than in 2012/13 planting season. The total LER was increased during 2011/12 than in 2012/13 planting season.

At Taung, the partial LER for maize under maize-cowpea intercropping with N fertilization was increased during 2011/12 than in 2012/13 planting season. The partial LER for maize under maize-cowpea intercropping with zero N fertilization was also increased during 2011/12 than in 2012/13 planting season. The partial LER for cowpea under maize-cowpea intercropping with N fertilization was higher during 2011/12 than 2012/13. The partial LER for cowpea under maize-cowpea intercropping with zero N fertilization was higher during 2012/13 than in 2011/12 planting season. The total LER for maize-cowpea intercropping with N fertilization was higher during 2011/12 than in 2012/13 planting season. The total LER for maize-cowpea intercropping with zero N fertilization were equal during 2011/12 and 2012/13 planting seasons. At Rustenburg, the partial LER for maize and cowpea under N and zero N fertilization were increased during 2011/12 than in 2012/13 planting season. The total LER of maize-cowpea intercropped with N and zero N fertilization were increased during 2011/12 than 2012/13 planting season.

Table 3.11. The Partial and total land equivalent ratio (LER) as affected by different treatment combinations during 2011/12 and 2012/13 planting seasons.

Site	**Season**	**Treatment**	**LER for maize**	**LER for cowpea**	**Total LER**
Potch	2011/12	MIC/N-fert	0.4	0.7	1.1
		MIC/zero-N	0.9	0.7	1.6
	2012/13	MIC/N-fert	0.6	0.4	1.0
		MIC/zero-N	0.7	0.4	1.1
Taung	2011/12	MIC/N-fert	0.7	0.8	1.5
		MIC/zero-N	1.8	0.4	2.2
	2012/13	MIC/N-fert	0.3	0.6	0.9
		MIC/zero-N	1.3	0.9	2.2
Rust	2011/12	MIC/N-fert	1.2	0.4	1.6
		MIC/zero-N	0.7	0.5	1.2
	2012/13	MIC/N-fert	0.9	0.2	1.1
		MIC/zero-N	0.5	0.4	0.9

3.4. Discussion

The previous crops such as legumes crops in crop rotation systems might help to improve soil characters, organic matter and nitrogen (Clark *et al*., 1997). This implies that phenological maize growth such as days to tasseling might have improved due to crop rotation, since soil structure and fertility is improved by rotation. The early tasseling of maize applied with N fertilizer agrees with similar findings by Gajri *et al*. (1994) who reported that maize phenological parameters were significantly affected by the amount of N fertilizer. Rustenburg and Potchefstroom climatic factor such rainfall and temperatures were favourable for maize to reach tasseling earlier. This agrees with similar findings by Kirtok (1998) and Tufekci (1999) who reported that tasseling period might be vary based on variety, climate and environment. The early tasseling of maize during 2012/13 may have been attributed to favourable climatic factors during that period which took place in January as indicated in Table 3.1.

The early physiological maturity of maize planted on monocropping system may have been attributed to less competition of resources as compared to maize planted on intercropping system. The early physiological maturity of maize at Taung and Rustenburg may have been attributed to higher temperatures at those sites (Table 3.1). Birch *et al*. (2003) reported that higher temperatures after silking usually causes crop development to cease and are significant constraint to production. Higher temperatures shorten the real time (number of days) from silking to maturity. The early physiological maturity of maize applied with N fertilizer confirms the statements by Ali *et al*. (2011) that number of days to physiological maturity in maize increased as N application rate increased from 0-150 kg ha^{-1}.

The large leaf area under rotational system may have been attributed to improvement of soil structure due to the rise of total nitrogen after harvesting of previous cowpea, which was indicated on soil analysis report. The reduction in leaf area under intercropping system was not expected in this study. The contribution of N input by accompanied cowpea crop in intercropping was expected to increase the growth of maize. The large leaf area under N fertilizer plots agrees with similar findings by Adeleke and Haruna (2012), who reported that the significant response of maize leaf area to applied N fertilizer could be due to its role in promoting rapid vegetative growth and its direct effect on cell division. The significant of this study on evaluation of cropping systems was that, even though intercropping with cowpea can be beneficial to maize, more of those benefits were found to be high in cowpea-maize rotation as compared to intercropping. Cowpea-maize rotation was found to increase the growth of maize due to high improvement of soil structure by previous cowpea in the cropping system. Birch *et al*. (2003) reported that lower rates of growth and development processes and final leaf size occur at lower and higher temperatures and rainfall limitation. Asim *et al.* (2012) reported variations for season, plant population and N fertilizer and interaction on leaf area. They further indicated treatment interactions of season x plant population, season x nitrogen, plant population x nitrogen and season x plant population x nitrogen to be significant on maize leaf area.

The higher number of leaves per plant of maize planted at Potchefstroom followed by Rustenburg may have been attributed to better soil structure and climatic factors, which led to better maize plant development. Stickler (1964) reported that number of leaves produced per maize plant was mainly affected significantly by cultivar. Maize plant height was expected to be higher due to the soil improvement by accompanied cowpea in the intercropping system, but it was not the case in this study. The taller maize plant height under rotational system may have been attributed to soil fertility, since crop rotation improves soil structure, increased soil organic matter and increased water use efficiency (Roder *et al.*, 1989; Varvel, 1994). The taller maize plants under maize planted on monocropping system may have been attributed to reduced competition of resources as compared to intercropping plots. The critical finding in this study was that, maize plant height was expected to be reduced under monocropping system, since monocropping of maize results in depletion of soil fertility, but it was higher under that system. Logrono and Lothrop (1997) reported that continuous cultivation of maize has contributed to the rapid depletion of soil N. The taller plant height under N fertilizer application corroborates the findings by Gozubenli (1997) and Tufekci (1999) who reported that plant height of corn was increased when application of N rates were increased. The taller maize plants during 2011/12 planting season may have been attributed to favourable rainfall and supplementary irrigation. Cakir (2004) stated that additional irrigation applied to corn plant during its flowering period led to increase in plant height. This agrees with similar findings by Boomsma *et al*. (2005) who reported that plant height variability generally varied with year, crop rotation and tillage treatment.

Due to taller plant height of maize at Potchefstroom, it was likely for the plants of that location to have large stem diameter. This agrees with similar findings by Abdelmula and Sabiel (2007) who reported that, there was positive and significant correlation between stem diameter and plant height. Carpici *et al*. (2010) reported that response of stem diameter to N fertilization was statistically significant. They further indicated that stem diameter increased up to 300 kg N ha^{-1} and then stayed stable at 400 kg ha^{-1}. The large stem diameter during 2011/12 planting season was due to the favourable climatic factors such as rainfall of 33.78 and 66.29 mm at Potchefstroom, 40.89 and 12.45 mm at Taung and 6.35 and 27.94 mm at Rustenburg during vegetative growth of maize (Table 3.1). The interaction effect of cropping system x season and site x nitrogen on stem diameter corroborate the findings by Adeleke and Haruna (2012) who reported the significant interaction, which occurred between previous crops and nitrogen fertilizer on maize growth.

The longer ear length, higher ear mass, kernel number per ear and grain yield under rotational cropping system may have been attributed to the improved soil structure by previous cowpea. According to Hoshikawa (1990) rotation improved soil physical properties and leguminous crops have ability to increase P availability through secretion of enzymes. This supported the statements by Murtaza *et al*. (2006) that crop rotation is beneficial for the improvement of physical, chemical and biological characteristics of soil and the replacement of organic remains and protection of climatic agents.

According to Carsky *et al*. (2001) cereal yield are almost always higher after a cowpea crop than after a cereal crop. Yield increased after cowpea compared with continuous cereal of the same species was 80% while it was only 31% for continuous cereal of differing species. Vesterager *et al*. (2007) reported that the yield of maize grown after cowpea monocrop was doubled and the N-uptake increased by 60% compared to maize following maize. Higher yield of cereal following cowpea have commonly been associated with higher amounts of inorganic soil-N following cowpea compared with cereal (Bagayoko *et al*., 2000). This implied that by rotating corn with cowpea, it significantly improved yield and yield components when compared to continuous corn. According to Higgs *et al*. (1976) and Welch (1976) corn grown in rotation with legume receives more N than corn grown continuously with no fertilizer. The higher ear mass, grain yield and field biomass under monocropping following rotation may have been attributed to the lack of competition for resources under sole cropping maize.

This confirms the statements by Mashingaidze *et al*. (2006) that monocropping maize had significantly higher yield than intercropping maize. According to Jellum and Kuo (1997) more N fertilizer was required to attain the critical biomass under continuous monocropping corn. The longer ear length, higher ear mass, kernel number per ear, hundred seed weight and grain yield under maize treated with nitrogen fertilizer may be attributed to fertility of soil due to improved soil organic matter. This agreed with similar findings by Osei-Bonsu and Asibuo (2003) who reported that application of N fertilizer generally resulted in increased maize yield regardless of the preceding legume. The reduction in maize yield under maize without N fertilizer agreed with similar findings by Lucas (1986) who reported that plants without applied N fertilizer gave significantly lower total dry matter and grain yield than plants with applied nitrogen. According to Morgado and Willey (2003) fertilizer N application rate had a significant effect on grain and total dry matter yield, as well as on total N uptake and grain N contents. N fertilizer reduced competitive effect of intercropping on maize yields and application of 50 kg N ha^{-1} is very efficient in increasing ear yield, as compared with unfertilized condition. The results revealed that maize-cowpea intercropping with zero N fertilizer were highly advantageous during 2011/12 than in 2012/13 planting season in term of land equivalent ratio. In this study the higher ear mass, kernel number per ear and grain yield under monocropping system were not expected. This finding contributed to the significance of comparing cropping systems towards improvement of maize yield.

This implied that, irrespective of continuous maize cropping, the yield performance was affected by the soil status of particular site, which means if the rate of soil fertility depletion was not high, the possibility of achieving yield under monocropping maize was high. Intercropped system in most studies yield more than monocropping maize, but in this study, cowpea-maize rotational cropping and monocropping maize performed better. The less maize yield under intercropping system might have been attributed to the competition for nutrients with legumes in plots of intercropping system. This implied that, the indeterminate cowpeas used in this study compete with maize significantly and affected the reproductive and maturity stages of maize.

The interaction effect of cropping system x site x N fertilizer on maize ear mass and grain yield contributed significantly towards the relevant of this study and yield improvement, since such interaction effect on maize yield was not revealed during previous studies. According to Omokanye *et al*. (2013) no significant on cropping system x nitrogen rate interaction effects were recorded on grain yield of maize. They further indicated that, the mean corn grain differed significantly between cropping system and nitrogen rates. According to Kumwenda *et al.* (1999) the analysis of variance of their results showed that the cropping system x nitrogen application interactions was not large enough to be significant on maize yield. According to Ali *et al*. (2011) interaction between nitrogen x variety were remained non-significant for all parameters of maize yield.

The higher stover yield under monocropping maize and cowpea-maize rotation corroborated the findings by Shafi *et al*. (2007) who reported that stover yield responded significantly to the previous legume compared with the previous cereal treatment. The good climatic conditions and soil structure of both sites may have contributed to high stover yield. The expectation in this study was to have higher stover yield also under intercropping system due to soil improvement by accompanying cowpea crop. N was expected to have significant effect on stover yield, and it was found to have no contribution on stover yield. According to Shafi *et al*. (2007) application of fertilizer N to maize increased stover yield by 167% over the nil N fertilizer treatment, and this was not the case with this study. The interaction effect of site x nitrogen fertilizer x season on stover yield also contributed towards the relevant of this study on biomass production, since such interaction was not reported during previous studies. Omokanye *et al*. (2013) reported that no significant cropping system x nitrogen rate interaction effects was recorded on stover yield of maize.

The partial LER for maize in both planting seasons at three sites was higher as compared to cowpea, and this agreed with similar findings by Yilmaz *et al.* (2008) who reported that partial LER of cowpea decreased as the proportion of maize increased in mix-proportions. The partial LER for cowpea at Taung were higher, showing the advantageous of cowpea, and this agreed with findings by Yilmaz *et al*. (2008) who reported that cowpea appears to have more beneficial land use efficiency in all mixture. In this study, the total LER were found to be higher than one showing the advantage of intercropping over sole stands in regards to the use of environmental sources for plant growth (Mead and Willey, 1980). The findings of this study were significant since application of N fertilizer has no influence on the improvement of total LER. The higher total LER at Taung was not expected since the site had high sand percentage.

3. 5. Conclusions and recommendations

In this study, cropping system played a vital role in terms of maize growth and yield. Rotational and monocropping were very advantageous as compared to intercropping. Cowpea-maize rotation improved maize plant growth as compared to intercropping and monocropping systems. Application of N fertilizer improved maize development. Maize development depends on site and season. Interaction effect of cropping system x site x nitrogen fertilizer on maize ear mass and grain yield contributed significantly towards yield improvement in this study. In this study, maize yield and yield components were higher under cowpea-maize rotational system, based on that, it is then recommended that cowpea-maize rotational cropping is better cropping system suitable for high maize production. LER of higher than one depend on site and season. The season with good climatic condition result in higher LER. Application of nitrogen fertilizer had no influence on total LER. Potchefstroom is recommended as a better site for maize production due to its adequate climatic factors and good soil structure.

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CHAPTER 4

CROP ROTATION AND INTERCROPPING COWPEA WITH MAIZE: COWPEA GROWTH AND YIELD

Abstract

Cowpea is grown mainly by small-scale farmers in developing regions and replenishes low fertility soil. A factorial experiment randomized in complete block design with three replications was conducted during 2011/12 and 2012/13 planting seasons. The experiment comprised of three cropping systems (Maize-cowpea rotation, monocropping cowpea and intercropped cowpea), three sites (Potchefstroom, Taung and Rustenburg) and two rates of N fertilizers applied in kg ha^{-1} at each site (0 and 20 at Potchefstroom, 0 and 17 at Rustenburg, 0 and 23 at Taung). Measured growth and yield parameters were days to 100% flowering, days to physiological maturity, number of leaves and nodules per plant, pods length, seeds per pod, pods weight at harvest, grain yield and stover biomass yield at harvest. Cropping system, site and N fertilizer had significant effects ($P < 0.05$) on cowpea plant growth and yield. Monocropped and maize-cowpea rotation significantly reached flowering and maturity earlier than intercropped cowpea. Monocropped and maize-cowpea rotation had significantly higher pods weight, grain yield and stover biomass yield. Cowpea planted at Rustenburg reached days to 100% flowering and maturity earlier than cowpea planted at other sites. Cowpea planted at Taung had significantly higher number of nodules per plant, longer pods length, higher number of seeds per pod, pods weight, grain yield and stover biomass yield at harvest than cowpea planted at other sites. The interaction effect of cropping system x site and site x season on yield parameters of cowpea contributed towards relevant of this study on cowpea yield improvement. Higher yield of cowpea is expected in the soil with high percentage of sand since cowpea is well adapted to sandy soil.

Key words: Crop rotation, grain yield, intercropping, nodules, nitrogen fertilizer.

4.1. Introduction

Cowpea is grown traditionally by small scale farmers as mixed or relay crop in association with cereals. Cowpea is a crop that play diverse role in contributing to the food security, income generation and soil amelioration for small-scale farming conditions (Amajoyegbe and Elemo, 2013). Analysing growth help to monitor the independent and interactive effects of various factors affecting yield (Harper, 1999). Ghanbari *et al.* (2009) reported that intercropped species might utilize the growth resources more efficiently than sole crops and resources may support a greater number of plants. It was further indicated that intercrops utilize plant growth resources such as light, water and nutrients more efficiently than the equivalent sole crops. In other studies, Cowpea growth parameters such as plant height and days to flowering were not significantly affected by intercropping (Alhaji, 2008). Cowpea was highly sensitive to high moisture condition because it enhanced high vegetative growth with negative effect on final yield (Jackai and Adalla, 1997). Cowpeas that are planted in intercropping flower later than those in sole crops (Moriri *et al*., 2010). Sole cowpea reached physiological maturity earlier than those planted in intercropping. They indicated that shading effect caused by taller maize plants delays flowering and maturity of cowpeas. The competitive relationships between the non-legume and the legume affected the growth of the leguminous crops in close proximity (Sangakkara, 1994). Fertilizer application resulted in significant improvement of plant height, number of leaves per plant and reduces days to flowering (Abayomi *et al*., 2008). Legumes required N at early vegetative stage and P fertilizers to enhanced the processes of nodulation in legumes (Atkins, 1996). The high amount of nitrogen application has been reported to reduce nodulation in legumes but as little as 20-25 kg N/ha has been reported to enhance early vegetative growth and increased nodulation without compromising the process of N fixation in legumes (Amba *et al*., 2013). Onuh and Donald (2009) reported that water is an essential component of root nodulation in plants and shortage of it results in reduced formation of nodules in the cowpea roots. According to Sears and Lynch (1951) N application reduces the mean nodule weight by more than 50%. Nodule reduction due to N application has long been known. According to Cameron (2003) seed can be inoculated with cowpea inoculum before sowing to ensure effective nodulation for N fixation, but this was not necessary if cowpea or other legume (mung beans, peanuts, stylos) have previously been grown in the same area.

According to Birteeb *et al*. (2011) intercropping system significantly reduced the biomass yield of the intercropped legumes. The yields advantage in cowpea sole crop was explained not only by the high plant density but also by the absence of competition with other crops (Ndakidemi and Dakora, 1997). Intercropping decreased bean biomass yield at all bean population and all N level as compared to sole cropping system. Stoop (1986) reported that the competitive effects of the cowpea intercrop, particularly on drought sensitive lands, were enhanced by increasing cowpea density and by lowering cereal density. According to Bullock (1992) increasing yield by practicing crop rotation had been known for many years. It has been assumed that the positive effects of rotations arised from the added N from legumes in the cropping system (Hoshikawa, 1990). Cowpea yield significantly responded to crop rotation, indicating that factors other than N alone contributed to the yield increase in cereal-legume rotation (Fatokun *et al*., 2002). Legume yields were consistently lower in continuous monoculture than when rotated with millet (Bationo and Ntare, 2000). According to Holland and Herridge (1992) cowpea was the best rotated crop, followed by sunflower, mungbean and soybean. Cowpea grain and stover yield were not influenced by nitrogen application as would be expected for a legume crop (Bagayoko *et al*., 1996). According to Hasan *et al*. (2010) biomass yield of cowpea increased with increasing level of N fertilizer. Biomass yield of beans increased progressively and significantly as bean population increased at all N level (Morgado and Willey, 2003). When pure N is applied at a rate of 45 kg/ha, it has ability to increase seed yield, plant height, number of pods per plant, number of seeds per pod and pod length (Azarpour *et al.*, 2011). The objective of the study was to determine the effect of site, cropping system and N fertilization on cowpea growth, yield and biomass yield.

4.2. Materials and Methods

4.2.1. Experimental sites

The study was conducted at three dryland sites in South Africa, namely the department of Agriculture experimental station in Taung situated at 27^0 30′S and 24^0 30′E, Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^0 26′S and 27^0 26′E and the Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg 25^0 43′S and 27^0 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*., 1968).

4.2.2. Experimental design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was a factorial experiment laid out in random complete block design (RCBD) with three replicates. The experiment consisted of three cropping systems (monocropping, rotational and intercropping), three sites Potchefstroom, Taung and Rustenburg and two levels of N fertilizer at each site, which were the amount of 0 and 20; 0 and 17; 0 and 23 kg N ha^{-1} applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

4.2.3. Data collection

Days to 100% flowering were recorded during 2011/12 and 2012/13 planting seasons. Three plants (one per middle row) were dug by their roots to determine nodule per plant during five weeks after planting, before flowering. Inoculation was performed during the first planting season of 2010/11 and no inoculants were applied to cowpea seeds during the second and third season of 2011/12 and 2012/13 planting season. Number of leaves per plant was recorded from three plant harvested in the middle rows prior to flowering period. Days to physiological maturity were recorded when the cowpea pods were matured and brown in colour.

Grain yield was recorded from the harvest area of 12 m^2 within each plot of rotational and monocropping cowpea. The harvest area of cowpea in intercropping plots was 8 m^2. Dried pods of cowpea were harvested, weight and recorded. Pods length and seeds per pod were recorded and thereafter pods were shelled and weighed for grain yield. The mass of grains per plot was converted to kg ha^{-1}. After harvesting of pods, the remaining plants at harvest area constituted for the field biomass yield.

4.3. Results

4.3.1 Days to 100% flowering

Cropping system had significant effect ($P \leq 0.001$) on days to 100% flowering of cowpea (Table 4.1 and Appendix 4.1.A). Maize-cowpea rotation reached days to 100% flowering significantly ($P < 0.05$) earlier at 68.7 days than monocropped and intercropped cowpea. N fertilizer application had significant effect ($P \leq 0.001$). Cowpea applied with N fertilizer reached days to 100% flowering significantly ($P < 0.05$) earlier at 67.1 days than cowpea without N fertilizer application. Days to 100% flowering of cowpea were significantly affected ($P \leq 0.001$) by site effect. Cowpea planted at Rustenburg and Potchefstroom had reached days to 100% flowering significantly ($P < 0.05$) earlier at 65.1 and 68.6 days respectively than cowpea at Taung. Cowpea planted during 2012/13 planting season had reached days to 100% flowering significantly ($P < 0.05$) earlier at 69.3 days than cowpea planted during 2011/12 planting season. Days to 100% flowering were affected by the interaction of cropping system x nitrogen ($P = 0.033$); cropping system x site ($P = 0.005$); and nitrogen x site ($P < 0.001$). Days to 100% flowering of cowpea were also affected by the interaction of nitrogen x season ($P = 0.003$); site x season ($P < 0.001$); and cropping system x site x season ($P = 0.047$).

Table 4.1. The interaction effects of cropping system, N fertilizer and site on days to 100% flowering of cowpea.

Cropping system	**Nitrogen**	**Site**	**Season**	
			2011/12	2012/13
Intercropped	Nitrogen	Potch	76.3 d	63.7 mno
		Rust	60.3 pq	66.3 jklm
		Taung	68.7 hij	76.3 d
	Zero-N	Potch	77.7 cd	64.3 lmn
		Rust	67.3 ijkl	70.7 gh
		Taung	76.0 d	80.3 bc
Monocropped	Nitrogen	Potch	72.3 efg	60.3 pq
		Rust	59.7 q	64.3 lmn
		Taung	68.0 hijk	75.3 de
	Zero-N	Potch	77.7 cd	65.0 klmn
		Rust	67.7 hijk	67.7 hijk
		Taung	77.3 cd	83.7 a
Rotational	Nitrogen	Potch	70.3 ghi	61.0 opq
		Rust	59.3 q	63.0 nop
		Taung	67.3 ijkl	74.7 def
	Zero-N	Potch	72.0 fg	62.0 nopq
		Rust	68.0 hijk	67.0 jkl
		Taung	77.0 d	82.3 ab
SEM	1.10			
LSD $_{(0.05)}$	3.1			

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.2. Days to physiological maturity

Cropping system had significant effect ($P \leq 0.001$) on days to physiological maturity of cowpea (Table 4.2 and Appendix 4.1.B). Monocropped cowpea and maize-cowpea rotation significantly ($P < 0.05$) reached days to physiological maturity earlier at 101.3 and 101.2 days respectively than intercropped cowpea. N fertilizer application had significant effect ($P \leq 0.001$) on days to physiological maturity. Cowpea applied with N fertilizer significantly ($P < 0.05$) reached days to physiological maturity earlier at 99.9 days than cowpea without N fertilizer application. Days to physiological maturity in cowpea were significantly affected by the site effect. Cowpea planted at Rustenburg and Potchefstroom had reached days to physiological maturity significantly ($P < 0.05$) earlier at 95.4 and 96.4 days respectively than cowpea planted at Taung. Cowpea planted during 2012/13 planting season had significantly ($P < 0.05$) reached days to physiological maturity earlier at 94.3 days than cowpea planted during 2011/12 planting season. Days to physiological maturity of cowpea were significantly affected by the interaction of cropping system x site; cropping system x site; cropping system x season; nitrogen x season; and site x season ($P < 0.001$). Days to physiological maturity on cowpea were also affected by the interaction of cropping system x nitrogen x site; cropping system x site and season x nitrogen, site x season ($P < 0.001$).

Table 4.2. The interaction effects of cropping system, N fertilizer and site on days to physiological maturity of cowpea.

Cropping system	**Nitrogen**	**Site**	**Season**	
			2011/12	2012/13
Intercropped	Nitrogen	Potch	102.7 hi	94.7 k
		Rust	102.7 hi	92.3 l
		Taung	124.0 b	111.3 d
	Zero-N	Potch	103.7 h	95.3 k
		Rust	108.0 ef	97.3 j
		Taung	133.0 a	112.7 d
Monocropped	Nitrogen	Potch	97.3 j	85.3 n
		Rust	101.3 i	78.0 p
		Taung	121.7 c	101.7 i
	Zero-N	Potch	106.0 g	90.0 m
		Rust	109.0 e	84.7 n
		Taung	133.7 a	107.0 fg
Rotational	Nitrogen	Potch	97.7 j	85.7 n
		Rust	101.7 i	78.0 p
		Taung	121.0 c	102.0 hi
	Zero-N	Potch	106.0 g	90.3 m
		Rust	108.7 e	83.3 o
		Taung	133.3 a	107.0 fg
SEM	0.57			
LSD $_{(0.05)}$	1.60			

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.3. Number of leaves per cowpea plant

Cropping system had significant effect ($P \leq 0.001$) on number of leaves per cowpea plant (Table 4.3 and Appendix 4.1.C). Monocropped cowpea and maize-cowpea rotation had significantly ($P < 0.05$) higher number of leaves per plant of 51.1 and 51.8, respectively than intercropped cowpea. Number of leaves per cowpea plant was significantly affected ($P < 0.001$) by the interaction of site x season.

Table 4.3. The interaction effects of cropping system, N fertilizer and site on number of leaves per cowpea plant.

Cropping system	**Nitrogen**	**Site**	**Season**	
			2011/12	2012/13
Intercropped	Nitrogen	Potch	49.2 bcdef	52.1 abcdef
		Rust	47.4 bcdef	22.0 g
		Taung	45.5 cdef	52.1 abcdef
	Zero-N	Potch	40.8 cdef	39.1 defg
		Rust	38.1 efg	34.1 fg
		Taung	34.0 fg	42.1 cdef
Monocropped	Nitrogen	Potch	41.7 cdef	51.7 abcdef
		Rust	56.8 abcd	42.3 cdef
		Taung	44.4 cdef	65.3 ab
	Zero-N	Potch	58.1 abc	49.9 bcdef
		Rust	55.5 abcde	43.9 cdef
		Taung	48.1 bcdef	55.5 abcde
Rotational	Nitrogen	Potch	58.8 abc	52.5 abcdef
		Rust	48.5 bcdef	44.7 cdef
		Taung	46.3 cdef	68.7 a
	Zero-N	Potch	45.6 cdef	54.8 abcde
		Rust	59.3 abc	42.8 cdef
		Taung	44.0 cdef	55.8 abcde
SEM	6.65			
LSD $_{(0.05)}$	18.7			

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.4. Number of nodules per cowpea plant

Number of nodules per cowpea plant was significantly affected ($P \leq 0.001$) by the site effect (Table 4.4 and Appendix 4.1.D). Cowpea planted at Taung had significantly ($P < 0.05$) higher number of nodules per plant of 12.2 than cowpea planted at Potchefstroom and Rustenburg. Cowpea planted during 2012/13 planting season had significantly ($P < 0.05$) higher number of nodules per plant of 12.1 than cowpea planted during 2011/12 planting season. Number of nodules per cowpea plant was significantly affected by the interaction of nitrogen x site ($P = 0.017$); site x season ($P \leq 0.001$); and cropping system x nitrogen x site ($P = 0.036$).

Table 4.4. The interaction effects of cropping system, N fertilizer and site on number of nodules per cowpea plant.

Cropping system	**Nitrogen**	**Site**	**Season**	
			2011/12	2012/13
Intercropped	Nitrogen	Potch	0.0 n	7.1 defghijk
		Rust	4.2 hijklmn	7.1 defghijk
		Taung	7.9 defghij	18.5 a
	Zero-N	Potch	2.9 jklmn	19.3 a
		Rust	3.3 ijklmn	7.5 defghij
		Taung	9.1 defgh	15.8 abc
Monocropped	Nitrogen	Potch	0.3 mn	5.9 efghijkl
		Rust	3.0 jklmn	7.3 defghij
		Taung	9.5 defg	17.7 a
	Zero-N	Potch	1.9 lmn	10.7 de
		Rust	4.5 ghijklmn	9.1 defgh
		Taung	5.4 fghijkl	16.3 ab
Rotational	Nitrogen	Potch	3.5 ijklmn	11.7 bcd
		Rust	4.3 hijklmn	8.1 defghi
		Taung	5.1 ghijklm	17.3 a
	Zero-N	Potch	2.2 klmn	11.0 cd
		Rust	2.9 jklmn	10.4 def
		Taung	5.8 efghijkl	17.3 a
SEM	1.79			
LSD $_{(0.05)}$	5.06			

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.5. Cowpea pod length

Cowpea pod length was significantly affected ($P \leq 0.001$) by site effect (Table 4.5and Appendix 4.1.E). Cowpea planted at Taung and Potchefstroom had significantly longer pod length of 17.6 and 17.3 cm respectively than cowpea planted at Rustenburg. Cowpea pod length was significantly affected ($P = 0.034$) by the interaction of cropping system x nitrogen.

Table 4.5. The interaction effects of cropping system, N fertilizer and site on cowpea pod length in centimetres.

Cropping system	**Site**	**N-fertilization**		**Zero-N**	
Season		2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	17.0 cdefghi	16.9 defghi	16.6 ghi	17.2 bcdefgh
	Rust	17.2 bcdefgh	16.6 ghi	16.7 fghi	16.0 i
	Taung	17.7 bcdef	16.8 efghi	18.0 abc	17.9 abcd
Monocropped	Potch	17.3 bcdefgh	18.8 a	16.9 defghi	17.3 bcdefgh
	Rust	17.2 bcdefgh	17.2 bcdefgh	16.7 fghi	16.3 hi
	Taung	18.1 ab	17.6 bcdefg	17.7 bcdef	17.8 abcde
Rotational	Potch	17.2 bcdefgh	17.4 bcdefg	17.4 bcdefg	17.2 bcdefgh
	Rust	16.0 i	17.1 bcdefgh	16.6 ghi	17.0 cdeghi
	Taung	17.5 bcdefg	17.3 bcdefgh	17.6 bcdefg	17.9 abcd
SEM	0.39				
LSD $_{(0.05)}$	1.11				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.6. Cowpea seed per pod

Cropping system had significant effect ($P = 0.024$) on cowpea seeds per pod (Table 4.6 and Appendix 4.1.F). Monocropped cowpea and maize-cowpea rotation had significantly ($P < 0.05$) higher number of seed per pod of 14.0 and 13.5 respectively than intercropped cowpea. Cowpea seed per pod was significantly affected ($P \leq 0.001$) by the site effect. Cowpea planted at Taung and Potchefstroom had significantly ($P < 0.05$) higher seed per pod of 14.4 and 13.5 respectively than cowpea planted at Rustenburg. Cowpea planted during 2011/12 planting season had significantly ($P < 0.05$) higher number of seed per pod of 13.9 than cowpea planted during 2012/13 planting season. Cowpea seed per pod was significantly affected by the interaction of site x season ($P = 0.012$) and the interaction of cropping system x site x season ($P = 0.004$).

Table 4.6. The interaction effects of cropping system, N fertilizer and site on cowpea seed per pod.

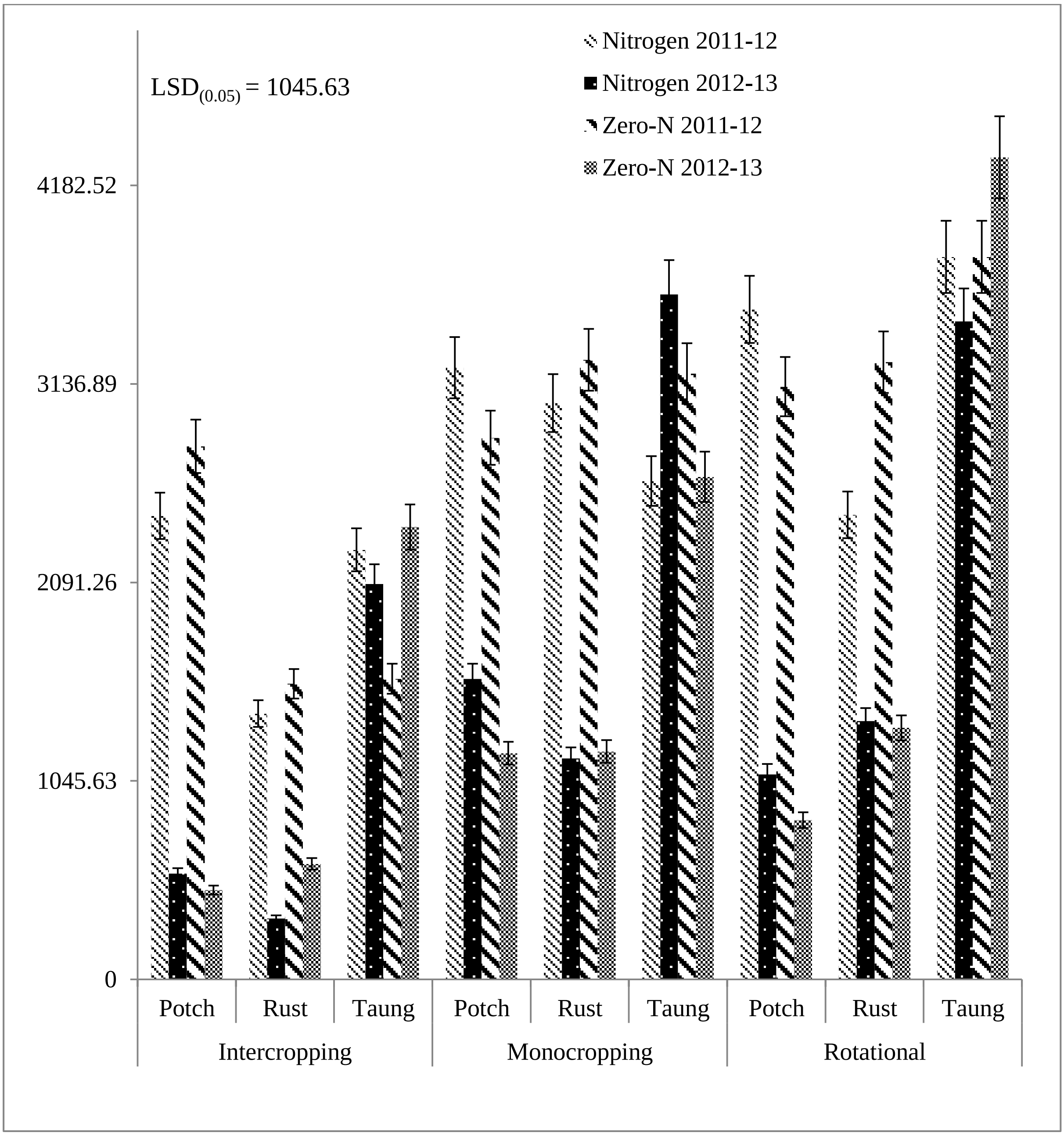
Cropping system	**Site**	**N-fertilization**		**Zero-N**	
Season		2011/12	2012/13	2011/12	2012/13
Intercropped	Potch	13.3 bcdef	12.5 def	13.2 bcdef	13.6 bcde
	Rust	14.3 abcd	11.7 efg	14.2 abcd	10.3 g
	Taung	13.4 bcde	13.6 bcde	13.6 bcde	14.4 abcd
Monocropped	Potch	13.3 bcdef	14.4 abcd	14.8 abc	12.6 def
	Rust	15.1 ab	12.7 def	13.2 bcdef	11.7 efg
	Taung	15.1 ab	14.9 abc	14.3 abcd	15.7 a
Rotational	Potch	14.0 abcd	13.1 cdef	14.3 abcd	12.7 def
	Rust	13.1 cdef	13.2 bcdef	11.4 fg	12.7 def
	Taung	14.8 abc	14.3 abcd	14.4 abcd	14.4 abcd
SEM	0.71				
LSD $_{(0.05)}$	1.99				

Means of the interaction effect within columns and rows followed by the same letter are not significantly different.

4.3.7. Cowpea pod mass at harvest

Cropping system had significant effect ($P \leq 0.001$) on cowpea pods mass at harvest (Figure 4.1 and Appendix 4.1.G). Monocropped cowpea and maize-cowpea rotation had significantly ($P < 0.05$) higher pod mass of 2465.5 and 2697.0 kg ha^{-1} respectively than intercropped cowpea. Cowpea pod mass was significantly affected ($P \leq 0.001$) by site effect. Cowpea planted at Taung had significantly ($P < 0.05$) higher pod mass of 2982.7 kg ha^{-1} than cowpea planted at Potchefstroom and Rustenburg. Cowpea planted during 2011/12 planting season had significantly ($P < 0.05$) higher pod mass of 2789.2 kg ha^{-1} than cowpea planted during 2012/13 planting season. Cowpea pod mass was significantly affected by the interaction of cropping system x site ($P = 0.013$) and the interaction of site x season ($P \leq 0.001$).

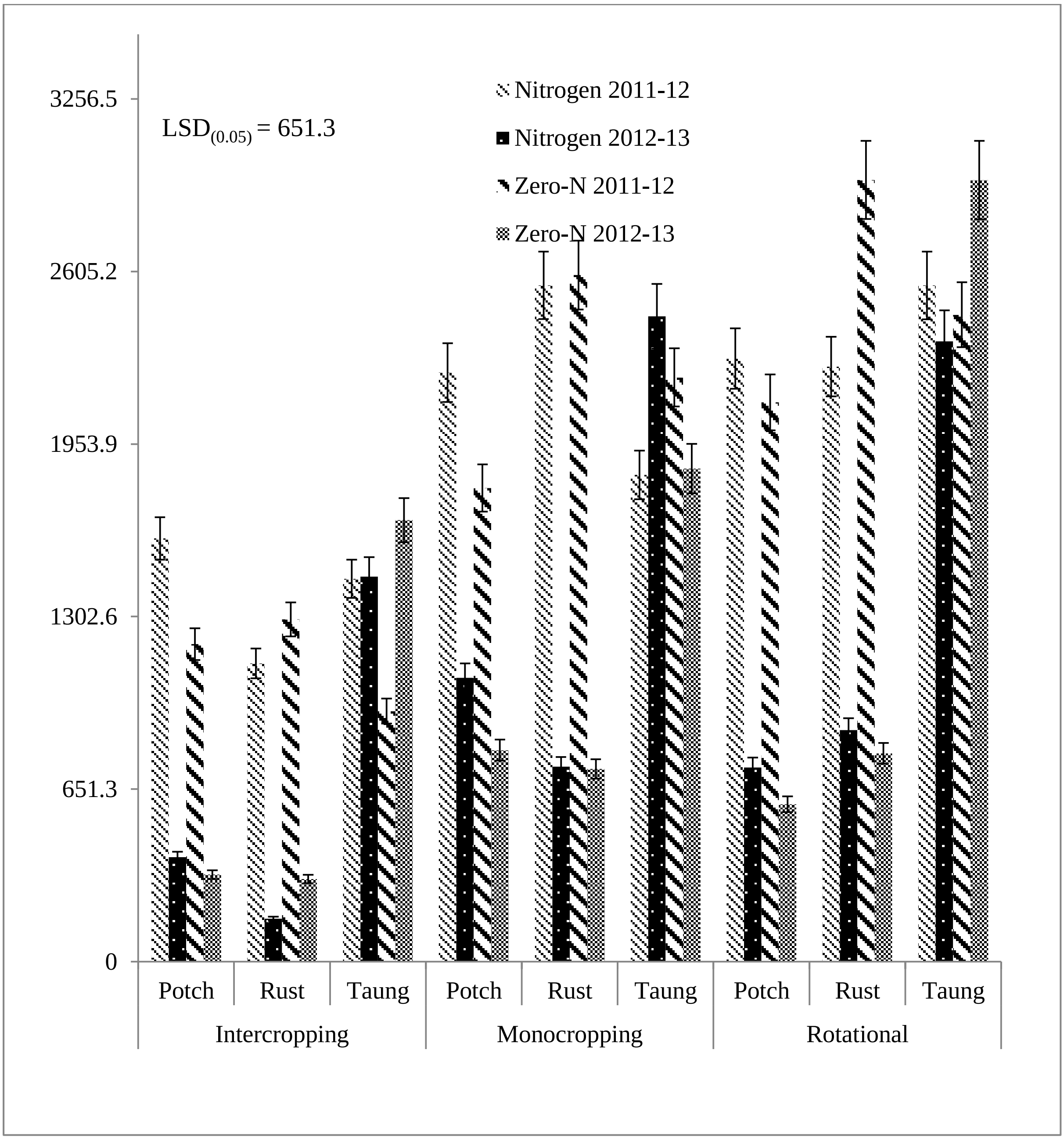
Figure 4.1. The interaction effects of cropping system, N fertilizer and site on cowpea pod mass (kg/ha) during harvest.



4.3.8. Cowpea grain yield

Cropping system had significant effect ($P \leq 0.001$) on cowpea grain yield (Figure 4.2 and Appendix 4.1.H). Monocropped cowpea and maize-cowpea rotation had significantly ($P < 0.01$) higher grain yield of 1735.8 and 1905.0 kg ha^{-1} respectively than intercropped cowpea. Cowpea grain yield was significantly affected ($P \leq 0.001$) by the site effect. Cowpea planted at Taung had significantly ($P < 0.05$) higher grain yield of 2011.5 kg ha^{-1} than cowpea planted at Potchefstroom and Rustenburg. Cowpea planted during 2011/12 had significantly ($P < 0.05$) higher grain yield of 1965.7 kg ha^{-1} than cowpea planted during 2012/13 planting season. Cowpea grain yield was significantly affected by the interaction of cropping system x site ($P = 0.037$); cropping system x season ($P = 0.026$) and site x season ($P \leq 0.001$).

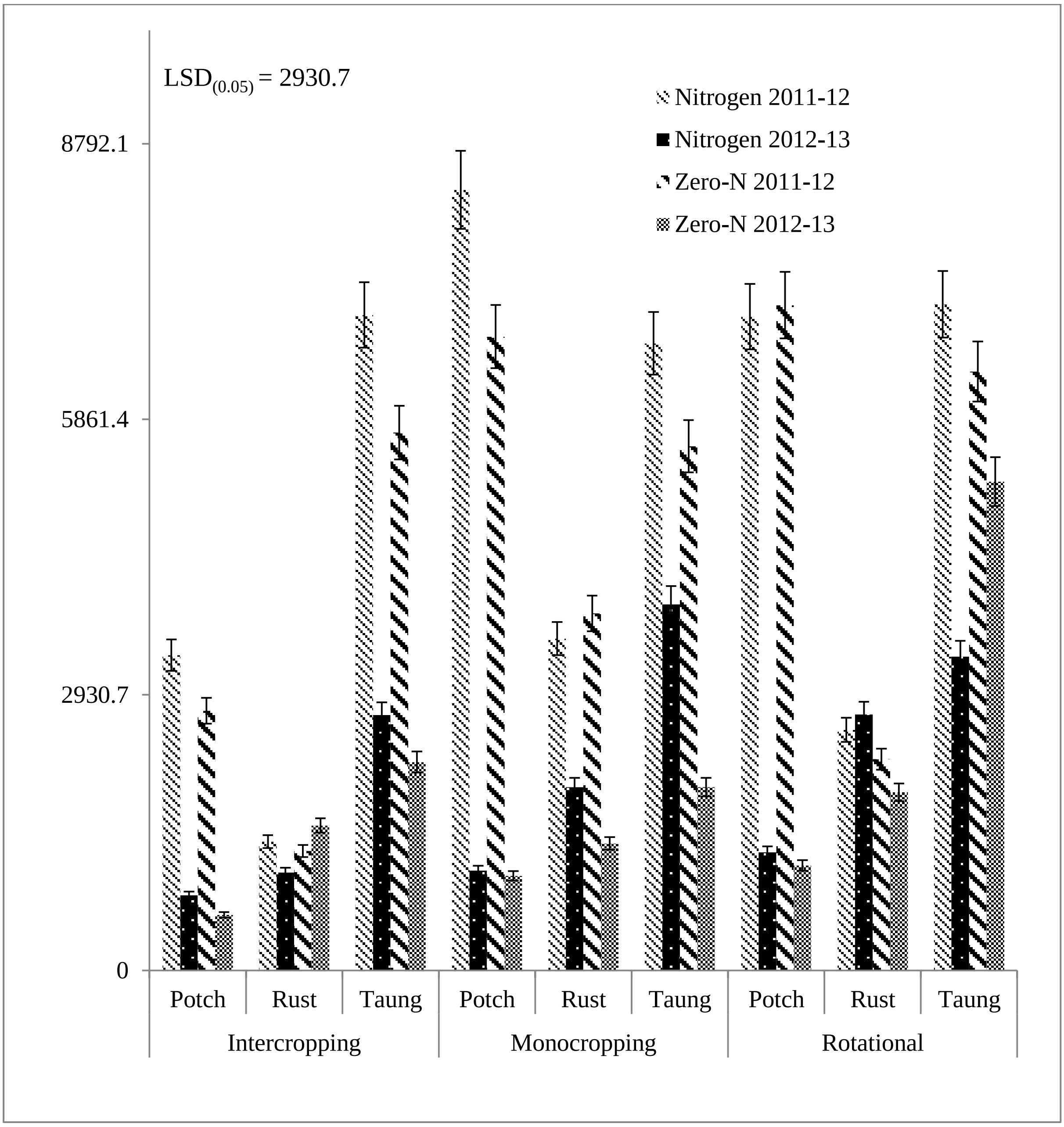
Figure 4.2. The interaction effects of cropping system, N fertilizer and site on cowpea grain yield (kg/ha) during harvest.



4.3.9. Cowpea stover biomass yield at harvest

Cropping system had significant effect ($P = 0.002$) on stover biomass yield (Figure 4.3 and Appendix 4.1.I). Monocropped cowpea and maize-cowpea rotation had significantly higher stover biomass yield of 3819.0 and 3984.7 kg ha^{-1} respectively than intercropped cowpea. Cowpea stover biomass yield was significantly affected ($P \leq 0.001$) by site effect. Cowpea planted at Taung and Potchefstroom had significantly ($P < 0.05$) higher stover biomass of 4809.0 and 3418.3 kg ha^{-1} respectively than cowpea at Rustenburg. Cowpea planted during 2011/12 planting season had significantly ($P < 0.05$) higher stover biomass yield of 4908.6 kg ha^{-1} than cowpea planted during 2012/13 planting season. Cowpea stover biomass yield was significantly affected ($P \leq 0.001$) the interaction of site x season.

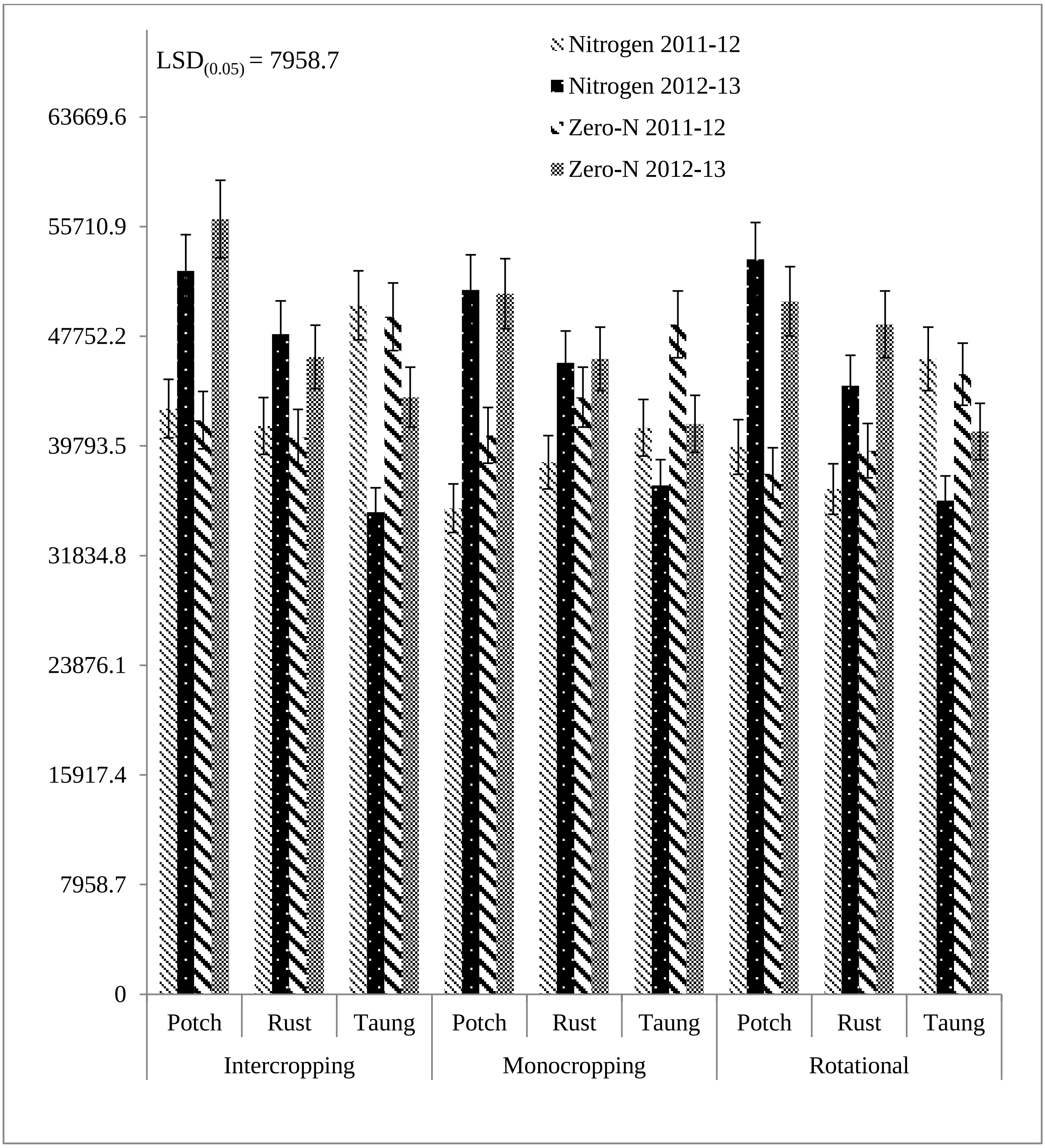
Figure 4.3. The interaction effects of cropping system, N fertilizer and site on cowpea stover biomass yield (kg/ha) during harvest.



4.3.10. Cowpea plant population per hectare at harvest

Cowpea plant population was significantly affected ($P = 0.014$) by the site effect (Figure 4.4 and Appendix 4.1.J). Cowpea planted at Potchefstroom had significantly ($P < 0.05$) higher plant population of 45983.8 ha^{-1} than cowpea planted at Rustenburg and Taung. N fertilizer application had significantly affected ($P = 0.037$) cowpea plant population. Cowpea without N fertilizer application had significantly ($P < 0.05$) higher plant population of 44992.3 ha^{-1} than cowpea applied with nitrogen fertilizer. Cowpea planted during 2012/13 had significantly ($P < 0.05$) higher plant population of 45918.2 ha^{-1} than cowpea planted during 2011/12 planting season. Cowpea plant population at harvest was significantly affected ($P \leq 0.001$) by the interaction of site x season.

Figure 4.4. The interaction effects of cropping system, N fertilizer and site on cowpea plant population per hectare.



4.4. Discussion

The earlier days to 100% flowering under cowpea planted on rotational system may have been attributed to improvement of soil structure caused by previous crops. The shading by maize under intercropping plots caused delay in days to 100% flowering. This contradicted the findings by Njouku and Muoneke (2008) who reported that there was no effect on cowpea intercropping on days to 50% flowering. Marschner (1995) reported that nitrogen deficiency lead to premature flowering. The differences in days to 100% among sites contradicted the findings by Rhoda (1989) who reported that flowering habit of cowpea may be genetically rather than environmentally controlled. Cowpea planted on Monocropping and rotational systems had reduced competition for resources such as sunlight and soil nutrients, and these resulted in earlier days to physiological maturity.

The earlier physiological maturity of cowpea planted on monocropping system confirms the statements by Moriri *et al*. (2010) that sole cowpea reached physiological maturity earlier than those planted in intercropping. According to Amujoyegbe and Elemo (2013) site and time of introduction of cowpea affected growth of cowpea. Higher number of leaves under monocropping and rotational cowpea may have been attributed to fertility of soil that led to increase in growth of cowpea. The production of more leaves under monocropping and rotational cowpea means higher light interception and more photo-assimilate production (Babaji *et al*., 2011).

Cowpea planted on monocropping might enhance soil nitrogen status and could benefits a subsequent cereal in legume/cereal crop rotation (Eaglesham *et al*., 1981). Blade *et al*. (1992) reported that cowpea growth was severely depressed by competition with other plants. The higher number of nodules per plant on cowpea planted at Taung may have been attributed to sandy soil type of the site. Dadson *et al*. (2003) reported that cowpea is a deep rooted crops and does well in sandy soils and more tolerant to drought than soybean. Dart (1973) reported that high soil temperatures, short days and low light intensity, low organic matter levels and presence of high available N and low soil moisture restricted the establishment of symbiosis. The higher number of seeds per pods, pod mass, grain yield and stover biomass under cowpea planted on monocropping and rotational systems may have been attributed to improved soil structure and fertility by cowpea. Vesterager *et al*. (2007) stated that the N-value of growing cowpea monocropping was equivalent to the application of 50 kg N ha^{-1} as mineral fertilizer. It was further indicated that cowpea cultivation result in a net N drain to the system and result in a considerable net N contribution to the system.

Cowpea planted on monocropping system might enhance soil nitrogen status and could benefit a subsequent cereal in legume/cereal crop rotation, provided the high N content stover is restored to the soil (Fujita *et al*., 1992). The main effect of legume was commonly attributed to an increase in soil N fertility as a result of biological N_2 fixation (Bado *et al*., 2011). The higher yield of cowpea planted on monocropping system than cowpea planted on intercropping system confirms the statements by Van Kessel and Roskoski (1998) that yield of intercropped cowpea was less than half that of monocropping cowpea at the same row spacing. Cowpea could not maintain its yield potential when intercropped with maize.

According to Egbe *et al*. (2010) intercropping depressed the number of branches per plant and the dry grain yield of cowpea, but did not influence the number of seed per pod and the pod length of cowpea. Better environmental factors such as rainfall and temperature during 2012/13 might have contributed towards higher number of nodules per plant, seed per pod, pods weight, grain yield and stover biomass yield. The lower cowpea yield at Potchefstroom and Rustenburg during 2012/13 planting season may have been attributed to severe birds attack during maturity period. The higher cowpea yield at Taung during both planting seasons may have been attributed to soil structure and climatic condition. According to Adeoye *et al*. (2011) cowpea has ability to tolerate drought and the fact that it fixes atmospheric nitrogen if allowed to grow on a poor soil. All cultivated cowpea varieties were considered warm season and adapted to heat and drought condition and better adapted to sandy soil (Akinyele *et al*., 1986).

4.5. Conclusions and recommendations

In this study, it has been shown that growth and yield of cowpea were higher under monocropping and rotational systems. This was due to lack of competitions for resources as compared to intercropping. The application of nitrogen fertilizer played a significant role on the growth of cowpea, but it did not affect the yield of cowpea. Intercropping of cowpea suppressed the growth and yield of cowpea. It is recommended that, cowpea should be planted as monocropping and rotated with cereals crops such as maize, sorghum and wheat, due to its high contributions towards soil structure and fertility improvement. Higher yield of cowpea is expected in the soil with high percentage of sand since cowpea is well adapted to sandy soil. In this study, Taung is recommended as the best site for cowpea production due to its soil structure.

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CHAPTER 5

EFFECT OF CROP ROTATION AND INTERCROPPING ON COWPEA CRUDE PROTEIN

Abstract

High protein contents in cowpea are considered as major advantage for its use in nutritional components. A factorial experiment randomized in complete block design with three replications was conducted during 2011/12 and 2012/13 planting seasons. The experiment comprised of three cropping systems (Maize-cowpea rotation, monocropping cowpea and intercropped cowpea), three sites (Potchefstroom, Taung and Rustenburg) and two rates of nitrogen fertilizers applied in kg ha^{-1} at each site (0 and 20 at Potchefstroom, 0 and 17 at Rustenburg, 0 and 23 at Taung). The experiment was conducted to investigate the effect of cropping system, site, and nitrogen fertilization on cowpea crude protein. The protein content was determined from green leaves harvested before flowering, immature green pods and seeds during reproductive stage and maturity. Results showed that cropping system ($P < 0.05$) had significant effect on cowpea leaf protein content. Intercropped cowpea significantly gave higher leaf protein (26.7%) content than rotational cowpea. Cowpea planted at Taung had significantly higher leaf protein (30.1%) content as compared to cowpea planted at other sites. Application of nitrogen fertilizer contributed to higher protein content of immature pods. Cowpea protein content differs among the different locations due to different soil types and climatic conditions.

Key words: cropping system, immature pods, leaf, protein content, seed.

5.1. Introduction

Cowpea plant parts such as leaves, pods and seeds are eaten by people and are rich in protein. Since cowpea is a major source of protein in diet of many people in sub-Saharan Africa, any effort made to increase the level of protein in the seed would improve the quality of the diet of the population (Boulter *et al*., 1975). Some people eat both fresh pods and leaves and the dried seeds are popular ingredients in various dishes (Davis, 1991). The seeds can also be cooked with meat, tomatoes and onions into a thick soup, eaten with pancake and bread. The nutritional profile of cowpea grain is similar to that of other pulses with a relatively low fat content and a total protein content that is two to four times higher than cereal and tuber crops (Timko and Singh, 2008). In some previous studies, total seed protein content ranges from 23% to 32% (Nielson *et al*., 1993). It is estimated that cowpea supplies about 40% of the daily protein requirements to most of the people in Nigeria (Muleba *et al*., 1997). Dry mature seeds are also suitable for boiling and canning. In many areas of the world, cowpea foliage was an important source of high quality hay for livestock feed (Tarawali *et al*., 2002). Phillips *et al*. (2003) found that the protein in grain legumes like cowpea has been shown to reduce low density lipoproteins that are implicated in heart diseases. Barret *et al*. (1997) reported that some varieties are suitable for harvesting as leaves, young pods and mature seeds, each over a long period for human consumption as well as for feeding livestock. If seeds are desired, leaf harvesting should cease before the pods begin to expand, since removal of too many young leaves at once will impair seed yield (Barret *et al*., 1997). Singh (1991) reported that cowpea grain, which was valued for its high nutritive quality and short cooking time, serve as a major source of protein in the daily diets of the rural and urban poor. Its tender leaves are eaten as spinach-like vegetable; while immature pods and seeds are also consumed as vegetable. The immature snapped pods are used in the same way as snap beans, often mixed with other foods. Elias *et al*. (2006) found that the protein efficiency ratio was higher in the cowpea samples than in beans. Since cowpeas have a higher nutritive value than common beans, and can be grown under many environmental conditions with higher yields, their use in human feeding should be recommended in developing areas of the world having protein in low quantity and quality (Elias *et al*., 2006). According to Shepherd and Kung (1996) crude protein has previously been shown to decline with increasing crop maturities. The influence of rotation and intercropping under different sites on cowpea protein content were not investigated extensively. In this study, the interaction effects of site, cropping system, and N fertilization on cowpea protein content were evaluated. The objective of this study therefore was to determine the effect of site, cropping system and N fertilization on edible cowpea plant parts protein content.

5.2. Materials and methods

5.2.1. Experimental sites

The study was conducted at three dryland sites in South Africa, namely the department of Agriculture experimental station in Taung situated at 27^0 30′S and 24^0 30′E, Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^0 26′S and 27^0 26′E and the Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg 25^0 43′S and 27^0 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*., 1968).

5.2.2. Experimental design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in random complete block design (RCBD) with three replicates. The experiment consisted of three cropping systems (monocropping, rotational and intercropping), three sites Potchefstroom, Taung and Rustenburg and two levels of nitrogen fertilizer at each site, which were the amount of 0 and 20; 0 and 17; 0 and 23 kg N ha^{-1}

applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

5.2.3. Chemical and statistical analysis

Cowpea green leaves were harvested from the middle rows before flowering. Cowpea immature pods were also harvested from the middle rows during reproductive stage. Both green leaves and immature pods were oven dried at 65°C for three days. At maturity, seeds were harvested and oven dried for three days. All cowpea plant parts were sent to ARC-IIC for analysis of nitrogen content. The method used to determine the nitrogen content of cowpea plant parts was Kjeldahl digestion procedure. The percent crude protein content was estimated using the relationship:

Crude protein % = N% x 6.25 (Ezeagu *et al*., 2002).

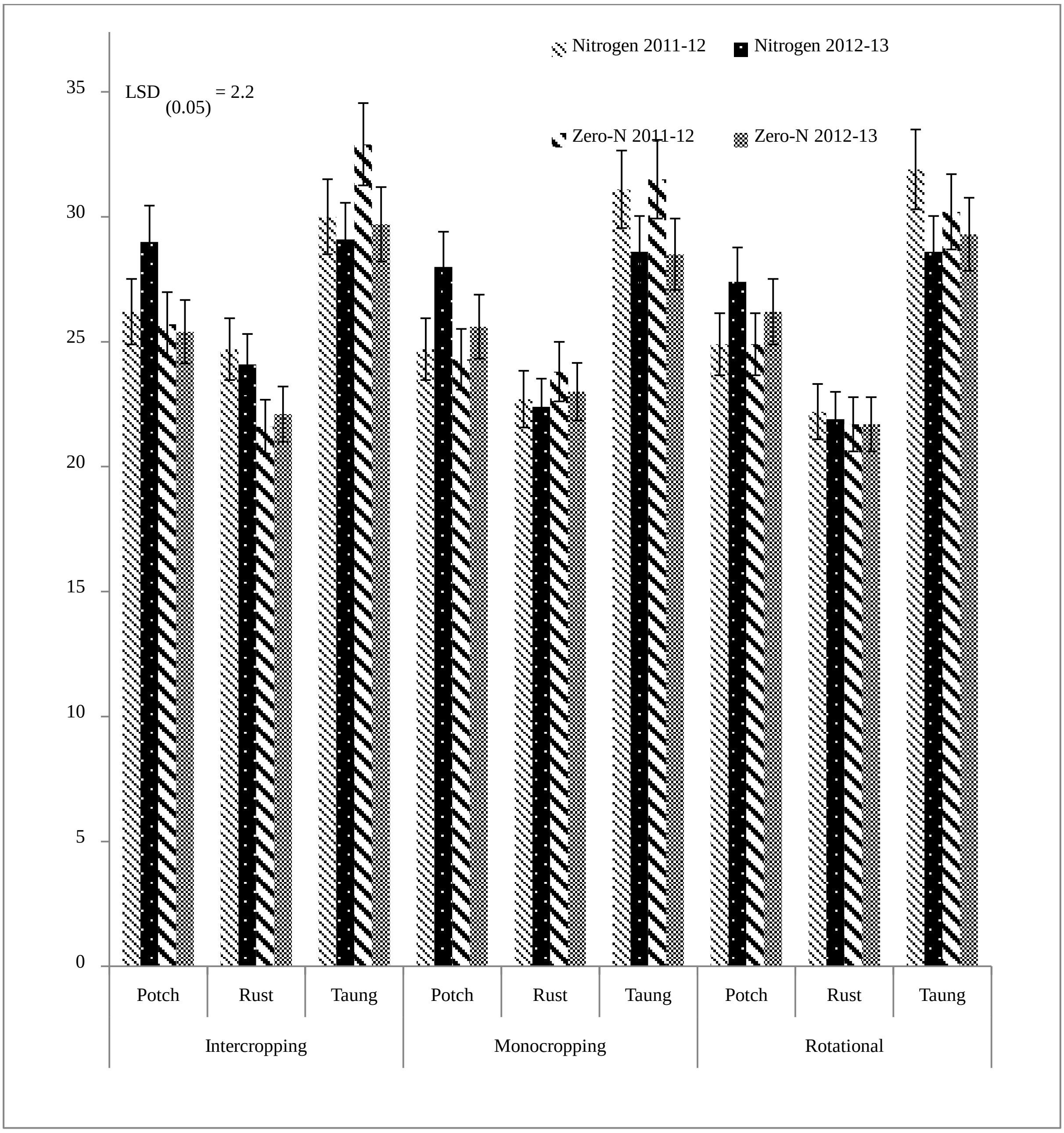
Analysis of variance was performed using GenStat 15th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered as significant statistically (Gomez and Gomez, 1984).

5.3. Results

5.3.1. Cowpea leaf protein

Cropping system had significant effect (P = 0.046) on leaf protein content (Figure 5.1 and Appendix 5.1.A). The intercropped cowpea had significantly (P < 0.05) higher leaf protein (26.7%) content than monocropped and rotational cowpea. Cowpea leaf protein content was significantly affected (P < 0.001) by site effect. Cowpea planted at Taung and Potchefstroom had significantly (P < 0.05) higher leaf protein content of 30.1 and 26.0% respectively than cowpea planted at Rustenburg. Cowpea leaf protein was significantly affected by the interaction of site and nitrogen (P = 0.024) and the interaction of site x season (P < 0.001). Cowpea protein content was also significantly affected by the interaction of cropping system x site x nitrogen (P = 0.012).

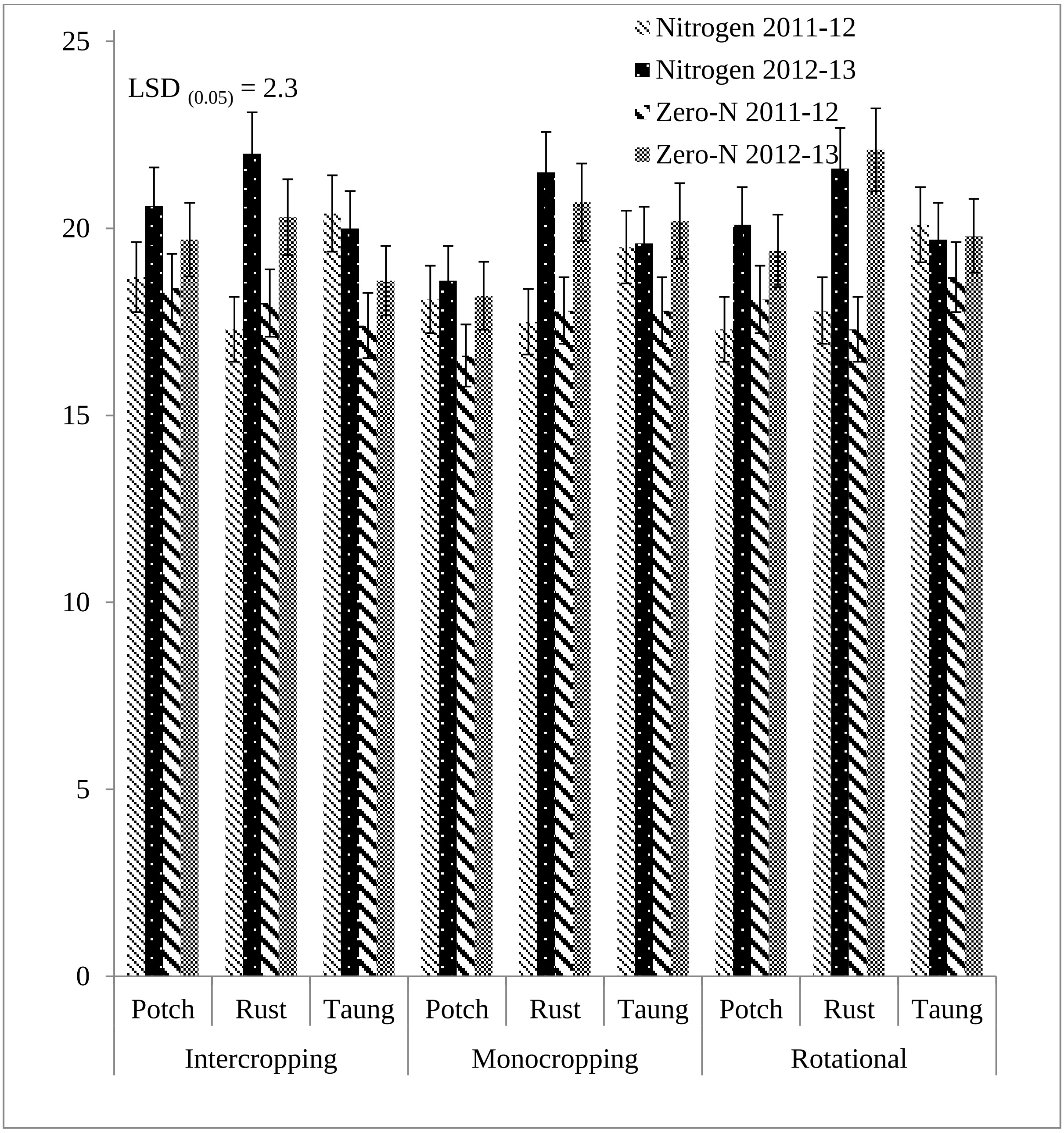
Figure 5.1. The interaction effects of cropping system, N fertilization and site on cowpea leaf protein content in percentages.



5.3.2. Cowpea immature pod protein

Cowpea immature pod protein was significantly affected ($P = 0.033$) by site effect (Figure 5.2 and Appendix 5.1.B). Cowpea planted at Rustenburg and Taung had significantly ($P < 0.05$) higher immature pod protein content of 19.5 and 19.3% respectively than cowpea planted at Potchefstroom. N fertilizer application had significant effect ($P = 0.024$) on cowpea immature pod protein. Cowpea applied with N fertilizer had significantly ($P < 0.05$) higher immature pod protein content of 19.5% than cowpea without N fertilizer application. Cowpea planted during 2012/13 planting season had significantly ($P < 0.05$) higher immature pod protein content of 20.1% than cowpea planted during 2011/12 planting season. Cowpea immature pod protein was significantly affected ($P < 0.001$) by the interaction of site x season.

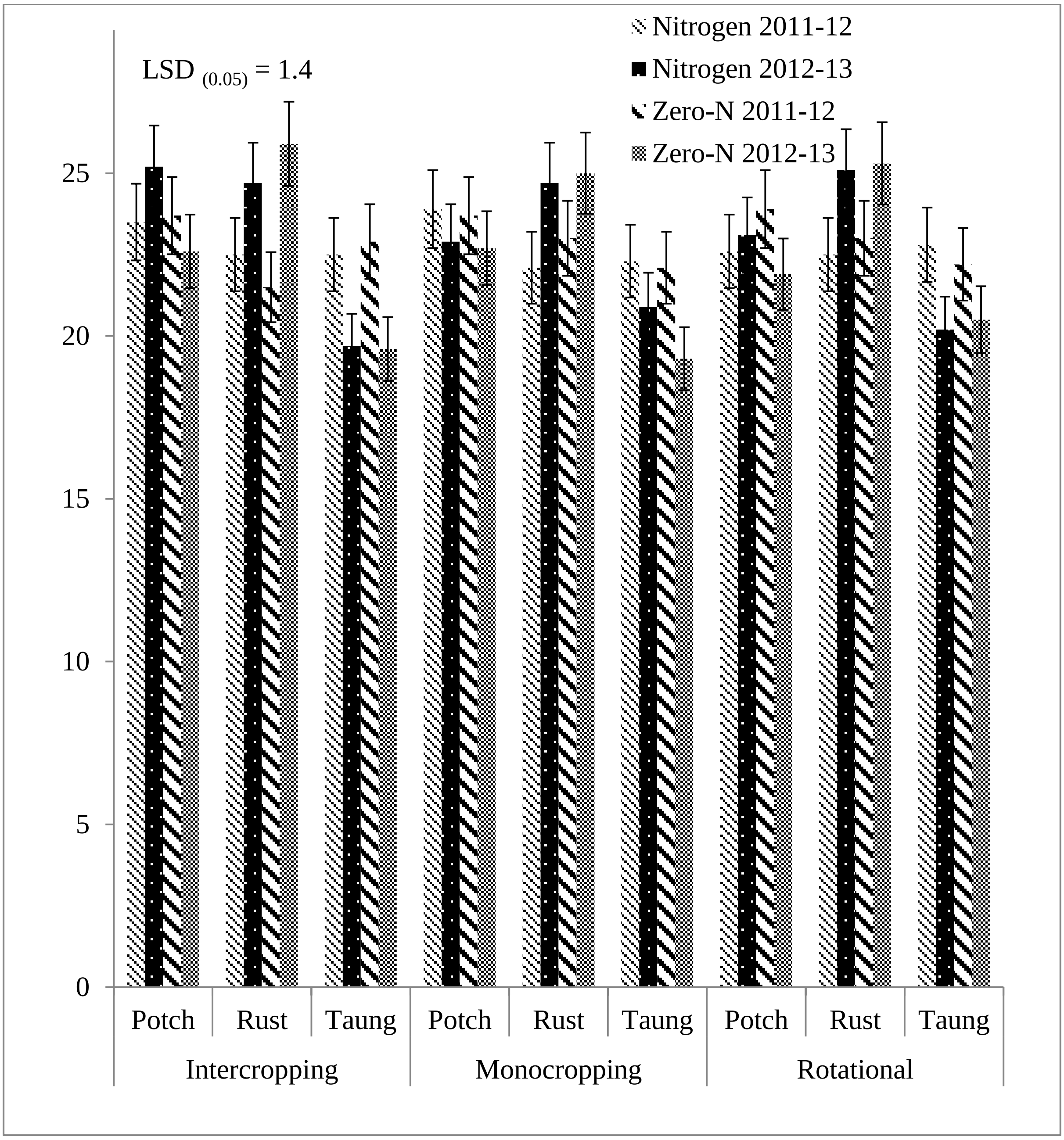
Figure 5.2. The interaction effects of cropping system, N fertilization and site on cowpea immature pod protein content in percentages.



5.3.3. Cowpea seed protein

Cowpea seed protein content was significantly affected ($P < 0.001$) by site effect (Figure 5.3 and Appendix 5.1.C). Cowpea planted at Rustenburg and Potchefstroom had significantly ($P < 0.05$) higher seed protein content of 23.8 and 23.3% than cowpea planted at Taung. Cowpea seed protein content was significantly affected by the interaction of site x season ($P < 0.001$), and the interaction of site x nitrogen x season ($P = 0.034$). Cowpea seed protein content was also significantly affected ($P = 0.033$) by the interaction of cropping system x site x nitrogen x season.

Figure 5.3. The interaction effects of cropping system, N fertilization and site on cowpea seed protein content in percentages.



5.4. Discussion

The higher leaf protein of cowpea planted on intercropping system might have been attributed to the shading by maize plants. According to Vu *et al*. (2006) UV-B radiation of 1.36 and 1.83 UV-Bseu can lead to decrease in soluble protein in leaf extract of legumes when exposed to such amount of radiation. This possibly affected photosynthesis, quality of photosynthates and protein partitioning. The results confirmed the statements by Musa *et al*. (2011) that intercropping increased the dry matter, ash, protein and fiber content of cowpea. Eskandari (2012) found that the forage quality of cowpea and mungbean in terms of crude protein content was significantly affected by cropping systems. This implied that intercropping played a role in crude protein content of cowpea leaves during vegetative stage of crops due to shading effects by maize.

The protein content of immature pods in this study was lower as compared to protein content of immature leaves and seeds during harvest maturity. The hypothesis was that, immature pods protein will be higher than seeds during harvest as stated by Shepherd and Kung (1996) that crude protein decline with increasing crop maturity. That findings contradicted with the findings of this study, where seed harvested at maturity had more protein content than immature pods harvested during reproductive stage and this contributed to the significant of this study towards cowpea protein improvement. The contribution of nitrogen fertilizer on cowpea immature pods confirmed the statements by Hasan *et al*. (2010) that, there was a progressive increase in the protein content of cowpea forage being influenced by the increasing level of nitrogen fertilizer. Ayub *et al*. (2010) found that the crude protein contents of cluster bean were significantly increased with increasing nitrogen rates. The maximum crude protein contents were obtained when nitrogen was applied at 45 kg ha^{-1}. It was further reported that the higher crude protein at higher nitrogen was mainly due to structural role of nitrogen in building up amino acid. Ayan *et al*. (2012) reported that at one location, average crude protein was different between years. The similar results were also observed in this study, where immature pod protein was higher in 2012/13 than 2011/12 planting season. This may have been attributed to different climatic conditions such as temperature and rainfall across the seasons.

The different of seed protein content in different locations may have been attributed to different soil types. The previous study by Lauriault *et al*. (2011) indicated that protein content of cowpea did not differ among soil types of sites. In this study, the significant finding is that, cowpea crude protein differs by site due to different in soil fertility and structure. Soil with high amount of nitrogen tends to have more cowpea crude protein content. The high leaf protein at Taung and Potchefstroom was due to soil nitrogen of those locations. Davis *et al*. (1991) reported that cowpea performs best on well drained sandy loam or sandy soil where pH is in the range of 5.5 to 6.5. Ayan *et al*. (2012) found that location and all the interactions in their study showed significant effect on cowpea crude protein.

The interaction effect of cropping system, site and nitrogen fertilizer on cowpea leaf and seed protein content contributed significantly towards cowpea quality improvement, since during previous studies, such interaction effects on cowpea protein content were not revealed. Mukhtar *et al*. (2010) reported that the comparison of cowpea between two seasons, nitrogen content was more in the dry season than in the rainy season. Protein content of the leaves was found to be higher in the dry season than in the rainy season. Wilson *et al*. (2014) reported the interaction of year x nitrogen to be significant on protein content of soybean cultivar. The protein concentration decreased linearly over years. Ayan *et al*. (2012) reported that no differences were found in cowpea crude protein among cultivars and years. Musa *et al*. (2011) reported that, intercropping and nitrogen fertilization significantly increased protein digestibility of seeds compared to untreated plants for two seasons.

5.5. Conclusions and recommendations

In this study, intercropping played a role on cowpea leaf protein content. Intercropping had ability to increase the crude protein content in cowpea immature leaves. Application of nitrogen fertilizer to cowpea contributed to higher protein content of immature pods. Cowpea protein content differed among the different sites due to different soil types and climatic conditions. Cowpea crude protein also differed by seasons. Crop rotation had no role on protein content of cowpea plant parts. In this study, it is recommended that, leaves and seeds should be treated as the best sources of crude protein for human and animal consumption, due to high percentage of protein in those plant parts.

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CHAPTER 6

MAIZE SEED QUALITY IN RESPONSE TO CROP ROTATION, INTERCROPPING AND NITROGEN FERTILIZATION

Abstract

Maize seed quality during storage can decline to a level that may make the seed unacceptable for planting purpose. A factorial experiment randomized in complete block design with three replications was conducted during 2011/12 and 2012/13 planting seasons. The experiment comprised of three cropping systems (cowpea-maize rotation, monocropping maize and intercropped maize), three sites (Potchefstroom, Taung and Rustenburg) and two rates of nitrogen fertilizers applied in kg ha^{-1} at each site (0 and 95 at Potchefstroom, 0 and 92 at Rustenburg, 0 and 113.5 at Taung). The experiment was conducted to investigate the effect of cropping system, site, and N fertilization on maize seed quality. Maize seeds harvested from Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher oil content of 4.4% than maize seeds harvested from Taung. Maize plots applied with N fertilizer had significantly ($P < 0.05$) higher seeds protein content of 8.7% than maize plots without N fertilizer application. Maize seeds harvested from Potchefstroom had significantly ($P < 0.05$) higher starch content of 71.8% than maize seeds harvested from Rustenburg and Taung. Cowpea-maize rotation and intercropped maize had significantly ($P < 0.05$) higher seed phosphorus content of 0.50 and 0.52% respectively than monocropped maize. In this study, site as factor played a pivotal role on quality of maize seeds. Maize seed quality was improved significantly by the interaction effect of site x season.

Key word: oil, phosphorus, protein, site, starch.

6.1. Introduction

High seed quality is necessary to establish crops, therefore cultivated seed should have vigour and related physiological characters (Farshadfar *et al*., 2012). Maximum seed vigour was attained at harvest maturity and not at physiological maturity (Wambagu *et al*., 2012). Fertilizer applications led to a significant increase in seed vigour and viability. Protein quality was a relevant factor for producers and consumers, especially when grain quality determined the final price of the commodity (Da Silva *et al*., 2005). Quality characteristics in maize such as protein contents in seed was improved with optimum N level (Amanullah *et al*., 2009). Low and high nitrogen dose had adverse effect on quality of maize (Stone *et al*., 1998). Application of various N levels significantly influenced seed protein content (Hammad *et al*., 2011). Without application of nitrogen, seed quality will extremely be decreased.

N application at silking increased kernel crude protein content, up to the application of 100 kg ha^{-1} nitrogen (Da Silva *et al*., 2005). This response showed that N applied during flowering was taken by the plant and accumulated in the grains. The advantage of increasing grain protein content with late N-side dressing was reducing kernel susceptibility to breakage at harvesting, a feature that allows greater aggregation of commercial value to the product (Tsai *et al*., 1992). The quality of maize was improved by intercropping due to more nitrogen availability for maize in intercropping (Eskandari and Ghanbari, 2009).

High oil maize contains higher energy content and more essential amino acids than conventional maize, which increased its value as animal feed (Lambert, 2001). The higher oil content of pollinator seed may influence seed germination and vigour. Seeds with high oil levels have often been associated with shorter longevity and greater deterioration than seeds with high starch content (Copeland and Mc Donald, 2001). The inability of oily seed to imbibe moisture and hold it tightly causes additional water to become excessive quickly and may contribute to more rapid deterioration of oily seed compared to starchy seed at comparable moisture levels (Thomison *et al*., 2002). The major chemical component of the maize kernel is starch, which provide up to 72 to 73 percent of the kernel weight (Boyer and Shannon, 1987). The composition of maize starch is genetically controlled. There was significant negative relationship between starch content and crude protein (Idikut *et al*., 2009). The crude protein decreased with increasing starch content of maize grain. Maize grown without fertilizer N promoted the greatest concentration of kernel starch, which had on average greater than kernels grown with the maximum N supply (Seebauer *et al*., 2010). Concentration of phosphorus in corn plants plays a critical role in intake of these nutrients by animal. Several studies have been done looking for the concentration of P in corn seed (Baker *et al*., 1970). The P concentration in corn hybrids depends on its genetics and environments where it is grown (Gautam *et al*., 2011). N fertilizer application reduced phosphorus content of maize and increased crude protein content significantly (Khogali *et al*., 2011).

Maize seed quality during previous studies was not extensively compared among intercropping and rotation in relation to nitrogen fertilization. These cropping systems were studied separately during previous studies. The hypothesis of the study was that, intercropping, cowpea-maize rotation and N fertilization will have no significant effect on maize seed quality. The interaction effect of site, cropping system and N fertilizer on maize seed quality was evaluated in this study. The objective of this study was to determine the effect of cropping system, site and N fertilization on maize seed quality.

6.2. Materials and methods

6.2.1. Experimental sites

The study was conducted at three dryland sites in South Africa, namely the department of Agriculture experimental station in Taung situated at 27^0 30′S and 24^0 30′E, Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^0 26′S and 27^0 26′E and the Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg 25^0 43′S and 27^0 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*., 1968).

6.2.2. Experimental design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in random complete block design (RCBD) with three replicates. The experiment consisted of three cropping systems (monocropping, rotational and intercropping), three sites Potchefstroom, Taung and Rustenburg and two levels of N fertilizer at each site, which were the amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1}

applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

6.2.3. Chemical and data analysis

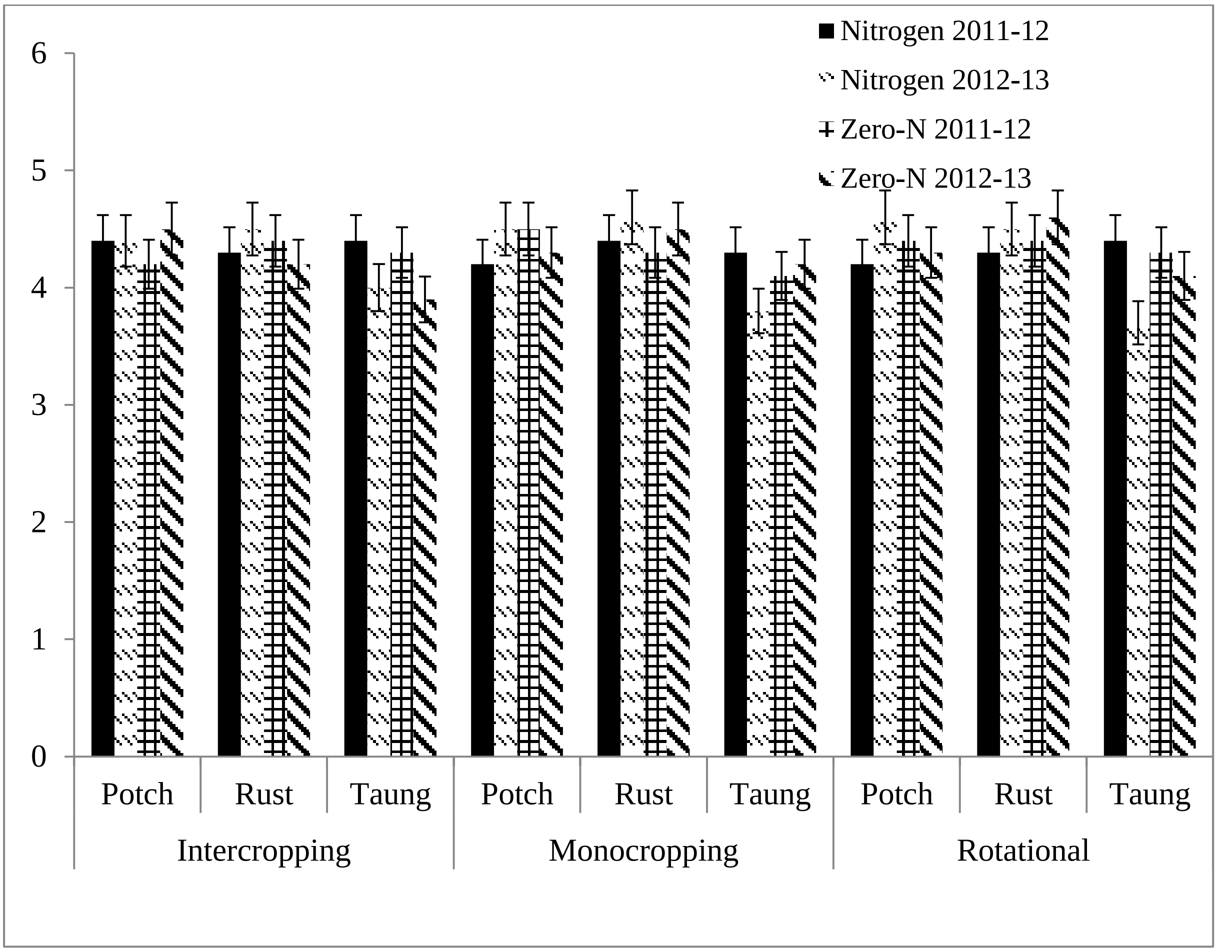
The seeds of maize were collected during harvest maturity and were analysed using Near Infrared Reflectance Grain Analyser (NIR) at ARC-GCI food quality laboratory. The seeds were analysed for starch, protein and oil content. The seeds were sent to ARC-IIC for analysis of phosphorus content. The method used to analyse phosphorus content at ARC-IIC laboratory was micro-kjeldahl digestion process. Analysis of variance was performed using GenStat 14th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered as significant statistically (Gomez and Gomez, 1984).

6.3. RESULTS

6.3.1. Maize seed oil content

Maize seed oil content was significantly affected ($P < 0.001$) by the effect of site (Figure 6.1 and Appendix 6.1.A). Maize seeds harvested at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher oil content of 4.4% than maize seeds harvested from Taung. Maize seed oil content was significantly ($P < 0.001$) affected by the interaction of site x season and the interaction of site x nitrogen x season. Maize seed oil content was also significantly ($P < 0.001$) affected by the interaction of cropping system x site x nitrogen x season.

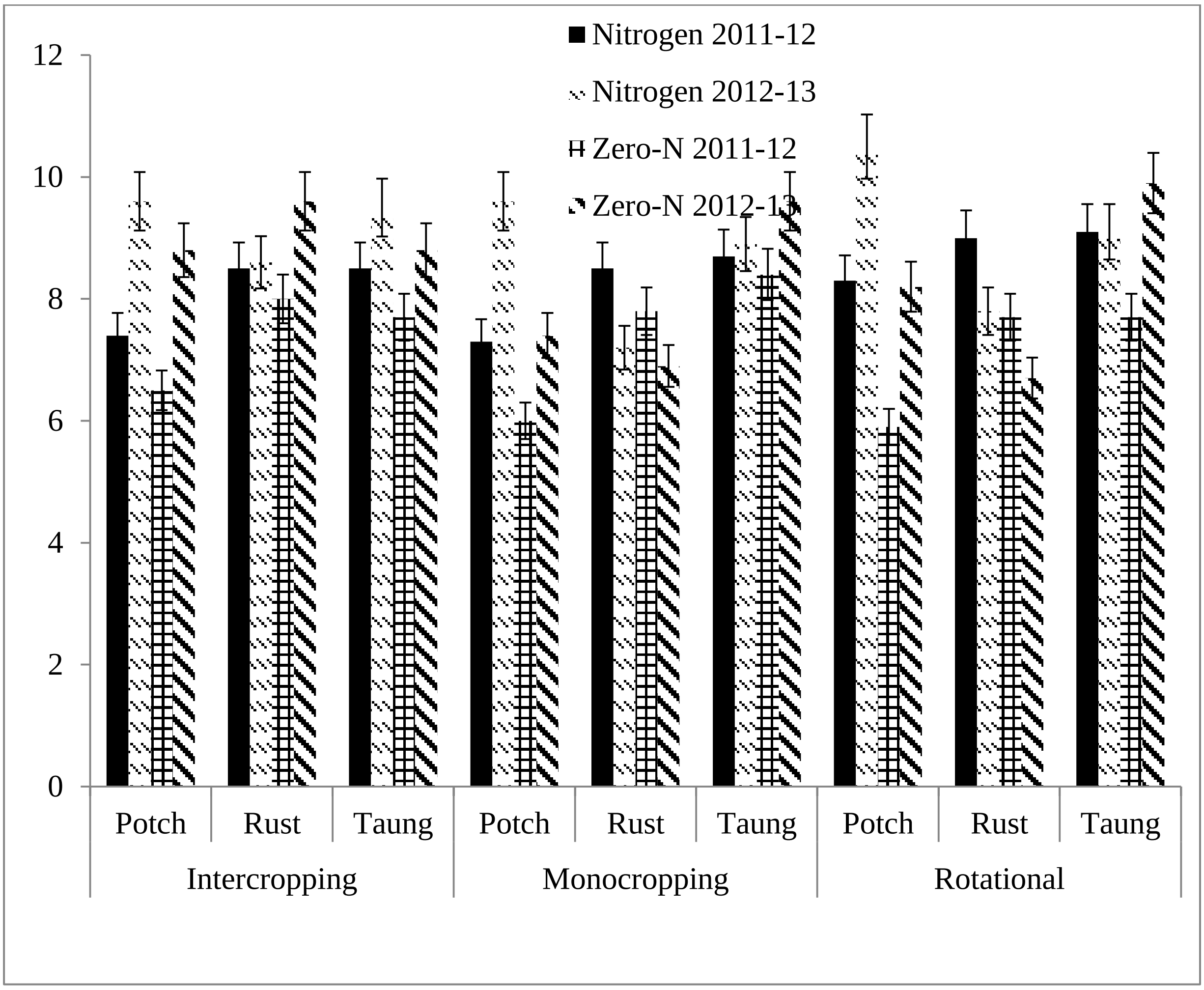
Figure 6.1. The interaction effects of cropping system, N fertilization and site on maize seed oil content in percentages.



6.3.2. Maize seed protein content

Maize seed protein content was significantly affected ($P < 0.001$) by the effect of site (Figure 6.2 and Appendix 6.1.B). Maize seeds harvested from Taung had significantly ($P < 0.05$) higher protein content of 8.8% than maize seeds harvested from Potchefstroom and Rustenburg. Application of N fertilizer had significant effect ($P < 0.001$) on maize seed protein content. Maize plots applied with N fertilizer had significantly ($P < 0.05$) higher seeds protein content of 8.7% than maize plots without N fertilizer application. Maize seed protein was also significantly ($P < 0.001$) affected by seasonal effect. Maize seeds harvested during 2012/13 planting season had significantly ($P < 0.05$) higher seed protein content of 8.7% than maize seeds harvested during 2011/12 planting season. Maize seed protein content was significantly affected ($P < 0.001$) by the interaction of site x nitrogen ($P = 0.013$) and the interaction of site x season.

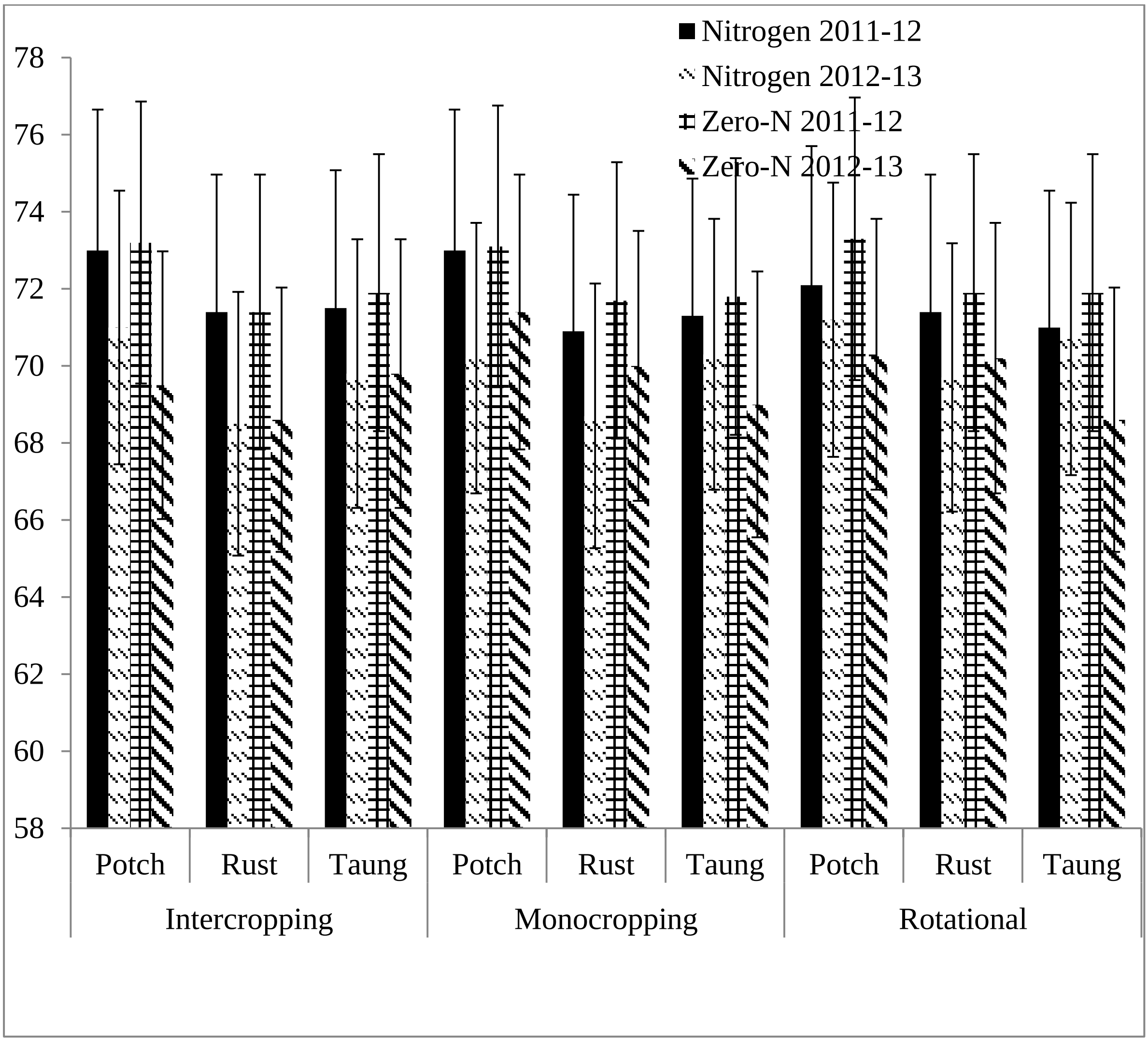
Figure 6.2. The interaction effects of cropping system, N fertilization and site on maize seed protein content in percentages.



6.3.3. Maize seed starch content

Maize seed starch content was significantly affected ($P < 0.001$) by site effect (Figure 6.3 and Appendix 6.1.C). Maize seeds harvested from Potchefstroom had significantly ($P < 0.05$) higher starch content of 71.8% than maize seeds harvested from Rustenburg and Taung. Maize seed starch content was significantly affected ($P < 0.001$) seasonal effect. Maize seeds harvested during 2011/12 planting season had significantly ($P < 0.05$) higher starch content of 72.0% than maize seeds harvested during 2012/13 planting season. Maize seeds starch content was significantly affected ($P = 0.037$) by the interaction of nitrogen x season.

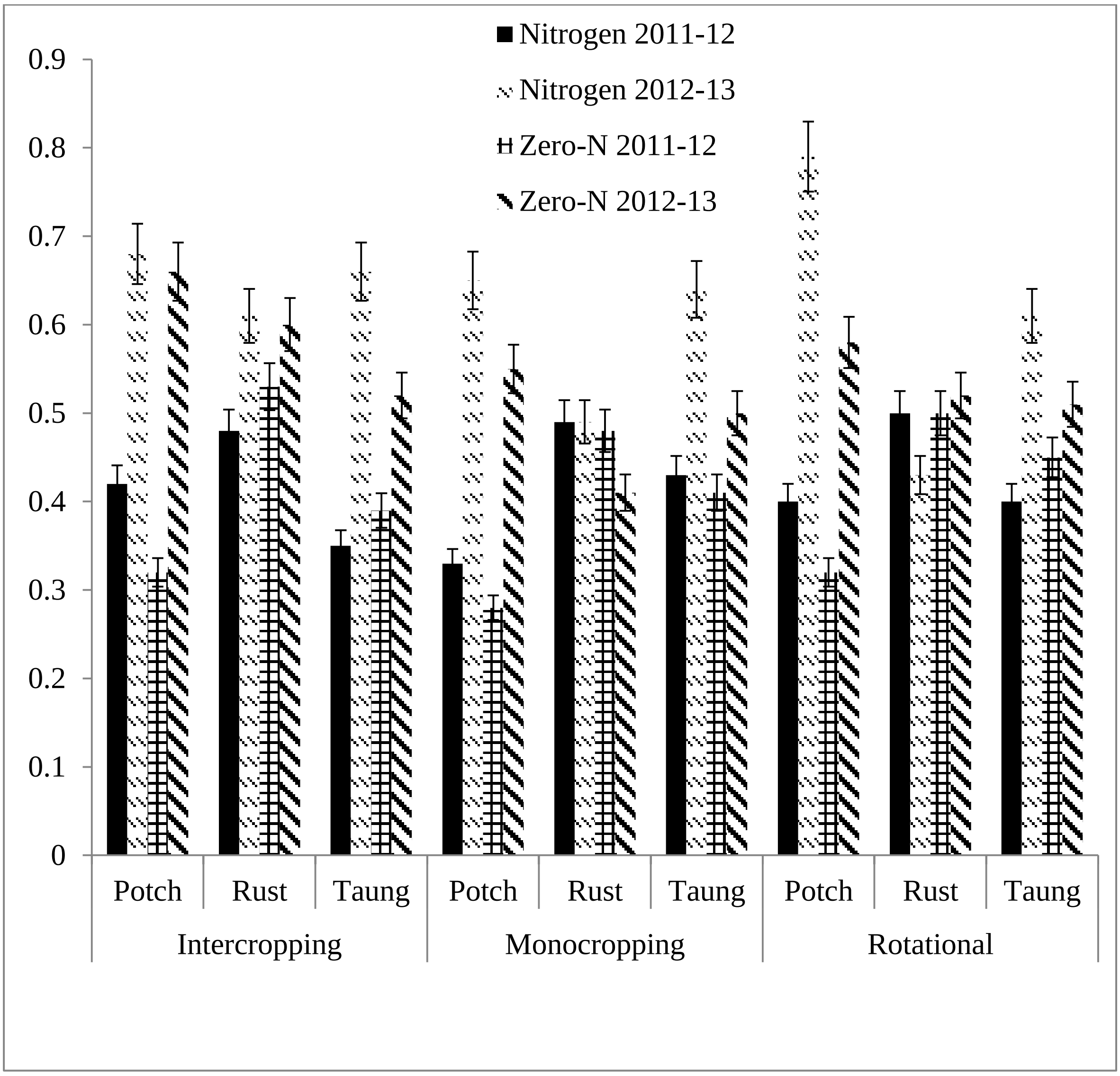
Figure 6.3. The interaction effects of cropping system, N fertilization and site on maize seed starch content in percentages.



6.3.4. Maize seed phosphorus content

Cropping system had significant effect ($P = 0.05$) on maize seed phosphorus content (Figure 6.4 and Appendix 6.1.D). Cowpea-maize rotation and intercropped maize had significantly ($P < 0.05$) higher seed phosphorus content of 0.50 and 0.52% respectively than monocropped maize. Application of N fertilizer had significant effect ($P = 0.001$) on maize seed phosphorus content. Maize plots applied with N fertilizer had significantly ($P < 0.05$) higher seed phosphorus content of 0.52% than maize plots without N fertilizer application. Maize seeds phosphorus content was significantly affected ($P < 0.001$) by season effect. Maize seeds harvested during 2012/13 planting season had significantly ($P < 0.05$) higher phosphorus content of 0.58% than maize seeds harvested during 2011/12 planting season. Maize seeds phosphorus content was significantly affected ($P < 0.001$) by the interaction of site x season.

Figure 6.4. The interaction effects of cropping system, N fertilization and site on maize seed phosphorus content in percentages.



6.4. DISCUSSION

6.4.1. Maize seed oil

The higher maize seed oil content at Potchefstroom and Rustenburg might have been attributed to the soil type. Shen *et al*. (2010) reported that maize seed oil content was determined by the oil concentration in the embryo, embryo size and oil in the endosperm. Maize seeds collected from those two locations had large grain size with large embryos. The differences in oil seeds across the locations corroborated the findings by De Geus *et al*. (2008) who reported that oil content was affected by location and genotype. Their findings revealed that oil content of seeds produced in a low input system was significantly higher than in conventional systems in both years of production. Maize seed oil content that was affected by the interaction effect of cropping system x site x nitrogen x season contributed towards significant of this study on maize grain quality improvement, since such interaction effect on maize seed was not reported previously. The study conducted by Riedell *et al*. (2009) indicated that year had no significant effect on kernel oil concentration and there were no significant N input x rotation interactions for kernel oil concentration in their study. The study conducted by Esmailian *et al*. (2011) also found interaction of irrigation x fertilizer treatments to have no significant influence of maize oil content.

6.4.2. Maize seed protein

The difference in maize seed protein across the sites contradicts the findings by De Geus *et al*. (2008) who reported that the protein content among genotype significantly differed for both years and in both farming system, but the protein content was not significantly different between locations. The higher seed protein content under plots applied with N fertilizer corroborated the findings by Da Silva *et al*. (2005), who reported that N application at silking also increased kernel crude protein content up to the application of 100 kg N ha^{-1}. This response showed that N applied during flowering was taken by the plant and accumulated in grains. They also indicated that possibility of increasing grain protein content with late N site dressing was reducing kernel susceptibility to breakage at harvesting. The difference in maize seed protein across the season corroborated the findings by Szmigiel (1998) who emphasized that protein content in grain was influenced by changes in weather condition during the vegetation period of maize. It was showed that the highest protein content in maize grain was obtained in dry and warm years, while in years of abundant precipitation high yields of grain were obtained at the lower protein content. The higher maize seed protein content at Taung was not expected in this study, due to sandy soil of that site. This finding implied that, it is possible to obtain high maize seed quality from sandy site, if good climatic conditions and supplementary irrigation were available during vegetative and reproductive stage of maize plant. Maize seeds protein content that was affected by the interaction effect of site x nitrogen and site x season was regarded as critical finding of this study, since such interaction effect on maize seed protein were not reported previously. The study by De Geus *et al.* (2008) revealed that location and location x genotype interactions had no effect on protein content suggesting that selection for high protein can be done in either conventional or low input cropping system.

6.4.3. Maize seed starch

The differences in soil types across the locations contributed to differences in maize seed starch content in this study. This agreed with similar findings by Wilkes *et al.* (2010) who reported that the soil type had the biggest impact on both protein and starch content, with the grains from grey vertosol soil having higher total insoluble and soluble protein contents and lower starch content. Starch content differed across the locations since quality of grain depend on interplay between the genetic characteristics of the plant and external factors that influence plant growth such as climate, soil and management practices. In this study, the different starch content among sites contradicted the findings by Buresova *et al*. (2010) who indicated that starch content was significantly affected by cultivar and year. They indicated that starch content was not significantly influenced by growing variant or site. The starch content of maize grains in this study differed across the seasons and this corroborated the findings by Buresova *et al*. (2010) who reported that starch content was significantly affected by weather during growing season. They indicated that warm weather during the growing season had a significant positive effect on starch content. This explains the reason of high starch at Potchefstroom due to high temperature during planting and vegetative growth of maize. In this study, the interaction of nitrogen x season was found to have significant effect on seed starch content while the findings by Riedel *et al.* (2009) reported that, no significant N input x rotation interaction for kernel starch.

6.4.4. Maize seed phosphorus

The higher maize seed phosphorus content under rotational and intercropping might have been attributed to improved soil structure by accompanying cowpea. The higher phosphorus content under intercropping system agreed with similar findings by Biareh *et al*. (2013) who revealed that intercropping culture had significant effect on phosphorus content. They indicated that the system with 100% corn + 15% of bean ratio treatment with mean of 0.55% had the most phosphorus content in grains. The high phosphorus content of maize seed under N-fertilizer treated plots may have been attributed to increased uptake of N by maize. Thiraporn *et al*. (2008) reported that weight of kernel phosphorus increased slightly with increasing rates of N fertilizer. The influence of nitrogen fertilizer on maize seed phosphorus content was also reported by Tarighaleslami *et al*. (2013), that different level of nitrogen fertilizer treatments had significant effect on phosphorus of seed and maximum phosphorus of seeds was gained by utilization of 180 kg ha^{-1} of nitrogen fertilizers. Maize seeds phosphorus content that was affected by interaction effect of site x season contributed towards significant of this study on quality improvement of maize. The findings by Tarighaleslami *et al*. (2013) indicated that phosphorus of seeds was significantly affected by the interaction of irrigation and application of nitrogen fertilizer treatment. Riedel *et al*. (2009) reported the significant N input x rotation interactions for maize kernel phosphorus.

6.5. Conclusions and recommendations

In this study, site as factor played a vital role on quality of maize seeds. Maize seeds collected at site with high clay soil content (Potchefstroom and Rustenburg) had high oil and starch content as compared to site with high sand. It was found that, maize seeds collected at site with high sand had higher protein content. It was then assumed that, soil type might have not been the only factor affected maize seed quality. The difference in seed quality across the site might have been affected by other climatic factors such as rainfall and temperature. The inclusion of legume on cropping system as intercrop or rotated with maize increased maize phosphorus content. The application of N fertilizer increased maize seed protein and phosphorus content. Maize seed protein, starch and phosphorus content depend on the season. The interaction of site x season played a significant role on this study, since it affected maize seed oil, protein and phosphorus content. In this study, it is recommended that, N fertilizer should be applied to maize in order to increase protein and phosphorus content for human and animal feeds. It is also recommended that, site with average clay content such as Potchefstroom be considered if quality of maize seed are desired, since that site produced maize seeds with high oil and starch content.

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CHAPTER 7

EFFECT OF MAIZE-COWPEA CROPPING SYSTEM ON SOIL CHEMICAL COMPOSITION

Abstract

Soil quality and structure are improved through soil organic carbon and organic matter builds up in the soil. The experimental design was factorial experiment laid out in random complete block design (RCBD) with two replicates. The experiment consisted of five management systems, namely, monocropping cowpea, Monocropping maize, rotational maize, rotational cowpea and intercropping maize-cowpea. The amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1} were applied on maize plots, while the amount of 0 and 20; 0 and 17; 0 and 23.5 kg N ha^{-1} were applied on cowpea plots at Potchefstroom, Rustenburg and Taung respectively. The laboratory analysis involved soil organic carbon, Bray 1-P, N-NO_3 and exchangeable K. Cropping system had significant effect ($P < 0.05$) on soil organic carbon; Bray 1-P and soil nitrate (N-NO_3). Soil collected from cowpea plots planted on monocropping and rotational systems had significantly higher organic carbon and soil nitrate than soil collected at other cropping systems. Soil collected at maize plots planted on monocropping and intercropping systems had significantly higher Bray 1-P than soil collected on other systems. Site had significant effect ($P < 0.05$) on soil organic carbon, Bray 1-P, N-NO_3 and K. Soil collected at Potchefstroom and Rustenburg had significantly higher organic carbon and exchangeable K than soil collected at Taung. Site also plays a role on soil organic carbon and chemical properties. The interaction effect of cropping system x site x season on Bray 1-P, N-NO_3 and exchangeable K had contributed towards the significant of this study on soil structure improvement.

Key words: Bray-1 P, exchangeable K, N-NO_3, Soil organic carbon.

7.1. Introduction

Soil organic carbon is the most important indicator of soil quality. Increasing soil organic carbon can improve soil health and help to mitigate climate change (Chan, 2008). According to Metson (1961) a productive soil should have an organic matter content of at least 4% (2.32% soil organic carbon). Mupangwa *et al*. (2003) indicated that sole cropping and intercropping had similar effect on soil organic carbon build up. Piha (1995) reported that organic carbon took over 10 years to increase by just 2.7%. Akinnifesi *et al*. (2007) found that soil organic carbon increased in the legume/maize intercrop, while in monoculture maize there was a slight decrease. According to Ameta and Sharma (2002) organic carbon contents varied with different intercropping treatments. Maize-wheat rotation, showed a decline in soil organic carbon of 3.84%, while soybean intercropping with maize in paired rows in 2:2 row ratio followed by wheat increased content of organic carbon in the soil as 0.65 and 0.67%, respectively compared to initial values of 0.52%. Anyanzwa *et al.* (2008) reported that fertilizer N addition significantly increased soil organic carbon in surface soils during the three cropping season. Higher soil organic carbon contents were obtained in treatments receiving 60 kg N ha^{-1}. Dahmardeh *et al*. (2010) reported that there was significant effect of cropping system on nitrogen, potassium and phosphorus content of soil. It was further indicated that the lowest of N, P and K was obtained at sole maize. Nitrogen, phosphorus and potassium content following sole maize was significantly less than that following sole cowpea and intercrops. Fujita and Ofosu-Budu (1994) reported that biological N fixation played an important role in the N uptake of cereal-legume intercropping. Seran and Brintha (2010) found that intercrop maize with a legume are able to reduce the amount of nutrients taken from the soil as compared to a maize monocrop. During absence of nitrogen fertilizer, intercropped legumes will fix nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi *et al*., 2007). Omokanye *et al*. (2011) reported that the inclusion of legumes in rotations increased soil total N and mineral N at planting of maize, as well as the residual total N and mineral N at harvest. It was indicated that the increase soil nitrate is likely to be derived from the mineralization of legume residues, because of available high quality organic matter. Belay *et al*. (2002) reported that legumes in rotation, because of their deep roots, can increase the K level through relocation of the ion to the soil surface from deeper in the soil profile. Liebig *et al.* (2002) reported that nitrogen fertilizer had a greater influence on soil properties than crop sequence. In this study, soil organic carbon and chemical composition were evaluated under different sites of different soil and climate types, and also under different cropping systems of maize and cowpea in relation to nitrogen fertilization. The rates of chemical composition were compared based on different depth of soil under different seasons. While effort were geared towards studying the interaction effects on site, cropping system, nitrogen, soil depth and season on soil organic carbon and chemical composition. The objective of the study was to determine the response of soil organic carbon and soil chemical properties to different cropping systems.

7.2. Materials and methods

7.2.1. Experimental sites

The study was conducted at three dryland localities. The department of agriculture experimental station in Taung situated at 27^0 30′S and $24^0$30′E and Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27^0 26′S and 27^0 26′E. The Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg is situated at 25^0 43′S and 27^0 18′E. The ARC-GCI experimental station has clay percentage of 34 and receives mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2°C during planting (Macvicar *et al*., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an average mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg *et al*., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha *et al*., 1968).

7.2.2. Experimental design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in random complete block design (RCBD) with two replicates. The experiment consisted of five management systems, namely, monocropping cowpea, monocropping maize, rotational maize, rotational cowpea and intercropping maize-cowpea. The amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1} were applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. The amount of 0 and 20; 0 and 17; 0 and 23.5 kg N ha^{-1} were applied on cowpea plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

7.2.3. Data collection, laboratory procedure and analysis

Soil samples were collected at the depth of 0-15 and 15-30 cm. Soil samples were air-dried and grinded using mortar and pestle (porcelain). Samples were weight at the quantity of 0.5 g into the glass beakers with capacity of 250 cm^3. The laboratory procedure used to determine organic carbon was Walkley Black method (Walkley, 1935).

$$\text{Organic C\%} = \frac{\text{cm}^3\ \text{Fe}\ (\text{NH}_4)2\ (\text{SO}_4)_2\ \text{blank} - \text{cm}^3\ \text{Fe}\ (\text{NH}_4)_2\ (\text{SO}_4)_2\ \text{sample} \times M \times 0.3 \times f}{\text{Soil mass (g)}}$$

Where M = Concentration of Fe $(NH_4)_2$ $(SO_4)_2$ in mol dm^{-3}

$N\text{-}NO_3$, $N\text{-}NH_4$, phosphorus (Bray 1-P) and exchangeable K were analysed. Total nitrogen was determined according to the Kjeldah digestion procedure and $N\text{-}NO_3$ was determined following IM KCl extraction. Available P was determined using Bray I-P procedure described by Bray and Kurts (1945). Exchangeable K was extracted using neutral normal ammonium acetate solution and K concentration in solution read on atomic absorption spectrophotometer (AAS). Analysis of variance was performed using GenStat 14th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered as significant statistically (Gomez and Gomez, 1984).

Table 7.1. The results of soil chemical properties (mg kg^{-1}) of samples collected before planting at three sites.

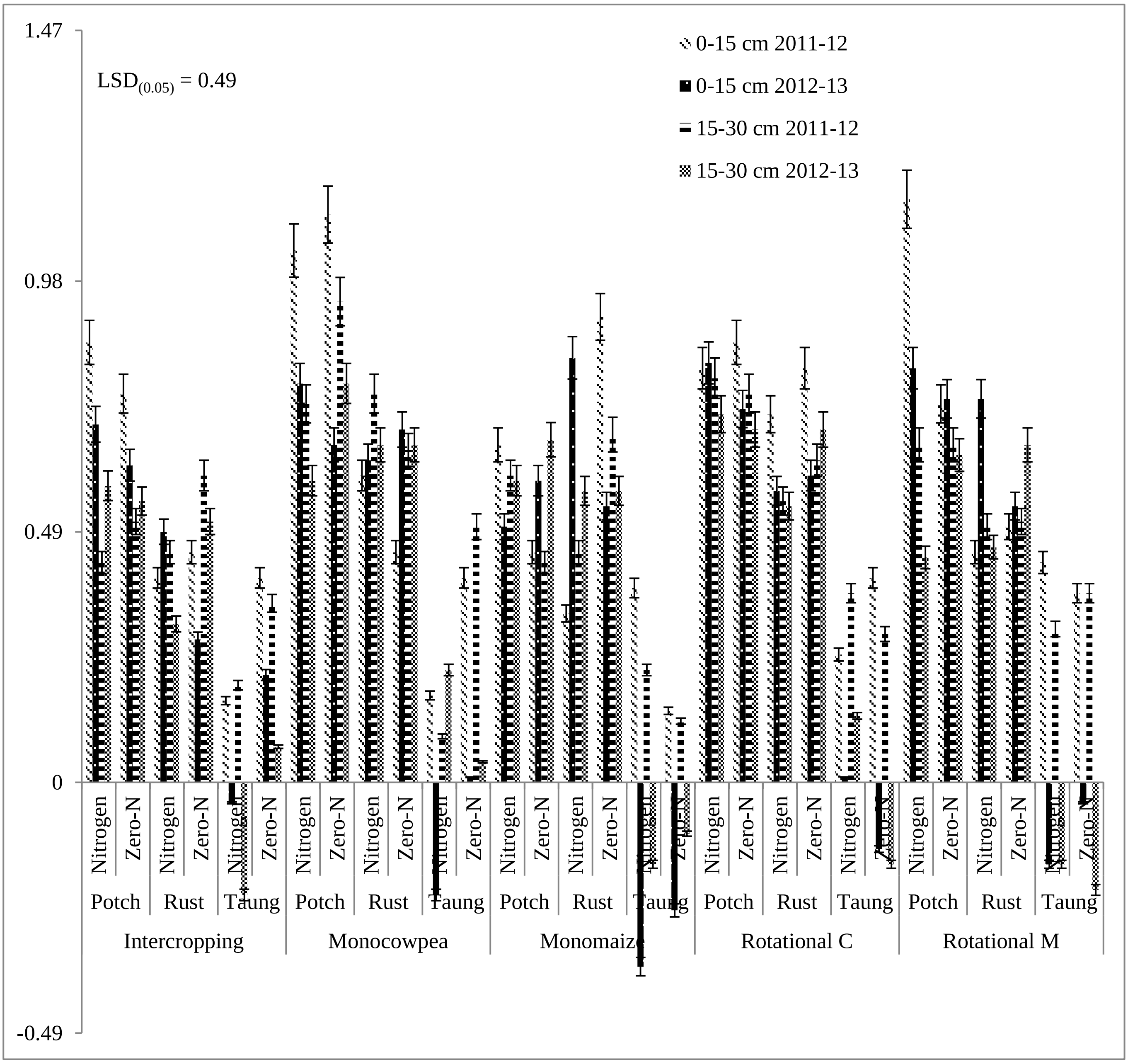
Site	**Chemical properties**	**0-15 cm**	**15-30 cm**
Potchefstroom	pH (KCl)	5.84	5.81
	$N\text{-}NO_3$	2.25	2.90
	$N\text{-}NH_4$	1.25	0.65
	P (Bray-1)	41	42
	K	348	318
Taung	pH (KCl)	6.51	6.63
	$N\text{-}NO_3$	2.50	1.50
	$N\text{-}NH_4$	0.75	0.75
	P (Bray-1)	7	7
	K	108	118
Rustenburg	pH (KCl)	4.87	5.07
	$N\text{-}NO_3$	3.25	1.40
	$N\text{-}NH_4$	0.75	0.50
	P (Bray-1)	4	2
	K	150	88

7.3. Results

7.3.1. Soil organic carbon content at harvest

Cropping system had significant effect ($P = 0.008$) on soil organic carbon (Figure 7.1 and Appendix 7.1.A). Cowpea plots planted on monocropping and rotational systems had significantly ($P < 0.05$) higher organic carbon of 0.54 and 0.52% respectively than other cropping systems. Site had significant effect ($P < 0.001$) on soil organic carbon. Soil collected at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher organic carbon of 0.70 and 0.57% respectively than soil collected at Taung. Soil collected during 2011/12 planting season had significantly ($P < 0.05$) higher organic carbon of 0.54% than soil collected during 2012/13 planting season. The interaction of site x season ($P < 0.001$) had significantly affected soil organic carbon.

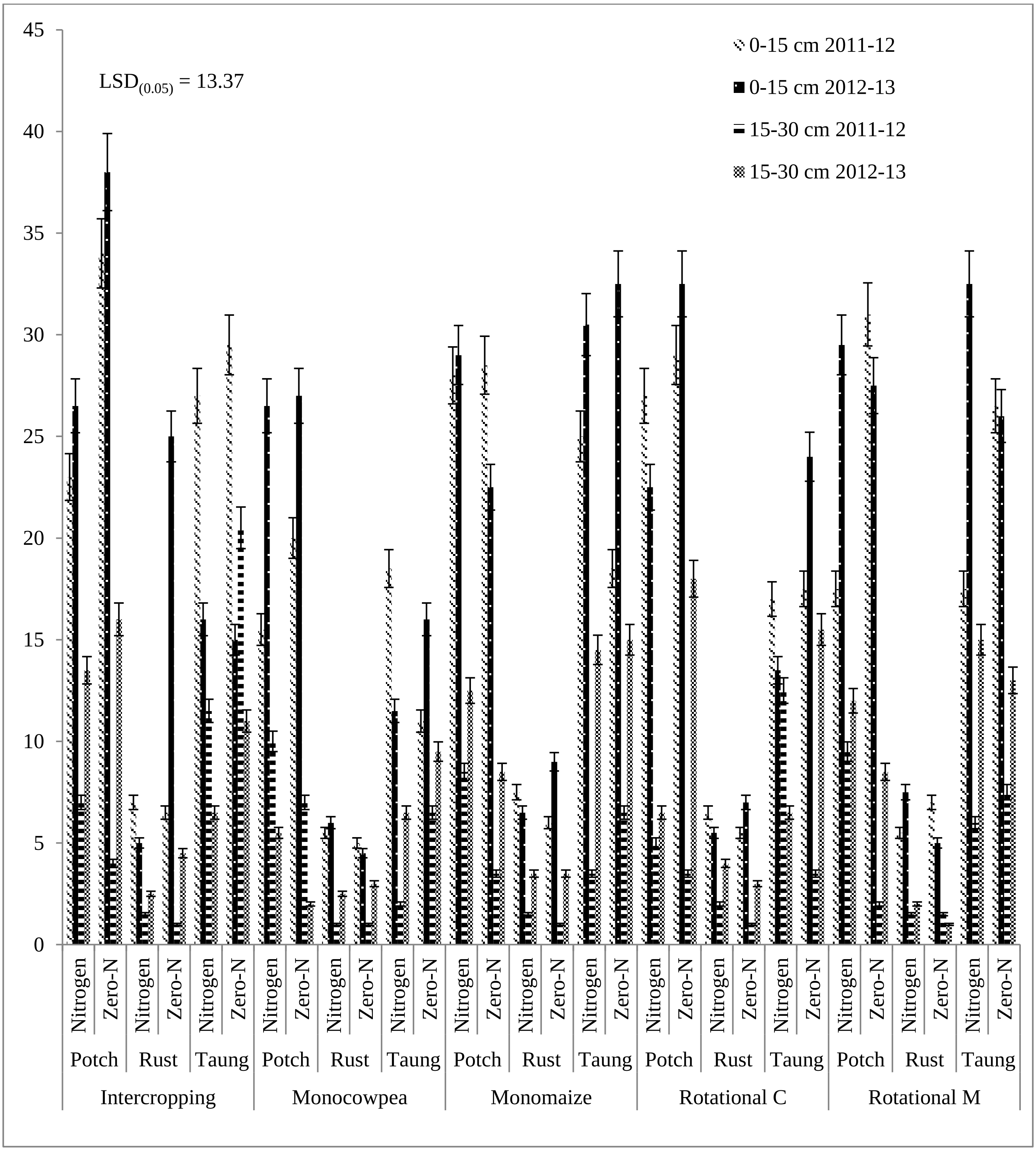
Figure 7.1. The interaction effects of cropping system, N fertilization, soil depth and site on soil organic carbon in percentages.



7.3.2. Soil Bray 1-P content at harvest

Cropping system had significant effect ($P = 0.003$) on soil Bray 1-P (Figure 7.2 and Appendix 7.1.B). Maize plots planted on monocropping and intercropping systems had significantly ($P < 0.05$) higher Bray 1-P of 13.56 and 14.67 mg kg^{-1} respectively than other cropping systems. Site had significant effect ($P < 0.001$) on soil Bray 1-P. Soil collected at Potchefstroom and Taung had significantly ($P < 0.05$) higher Bray 1-P of 17.45 and 15.46 mg kg^{-1} respectively than soil collected at Rustenburg. Soil Bray 1-P was significantly ($P < 0.05$) higher at the depth of 0-15 cm (18.39 mg kg^{-1}) than soil at the depth of 15-30 cm. Season had also showed significant effect ($P = 0.005$) on soil Bray 1-P. Soil collected during 2012/13 planting season had significantly ($P < 0.05$) higher Bray 1-P of 13.76 mg kg^{-1} than soil collected at 2011/12 planting season. The interaction of site x soil depth ($P < 0.001$) and interaction of cropping system x site x season ($P = 0.011$) had significantly affected Bray 1-P.

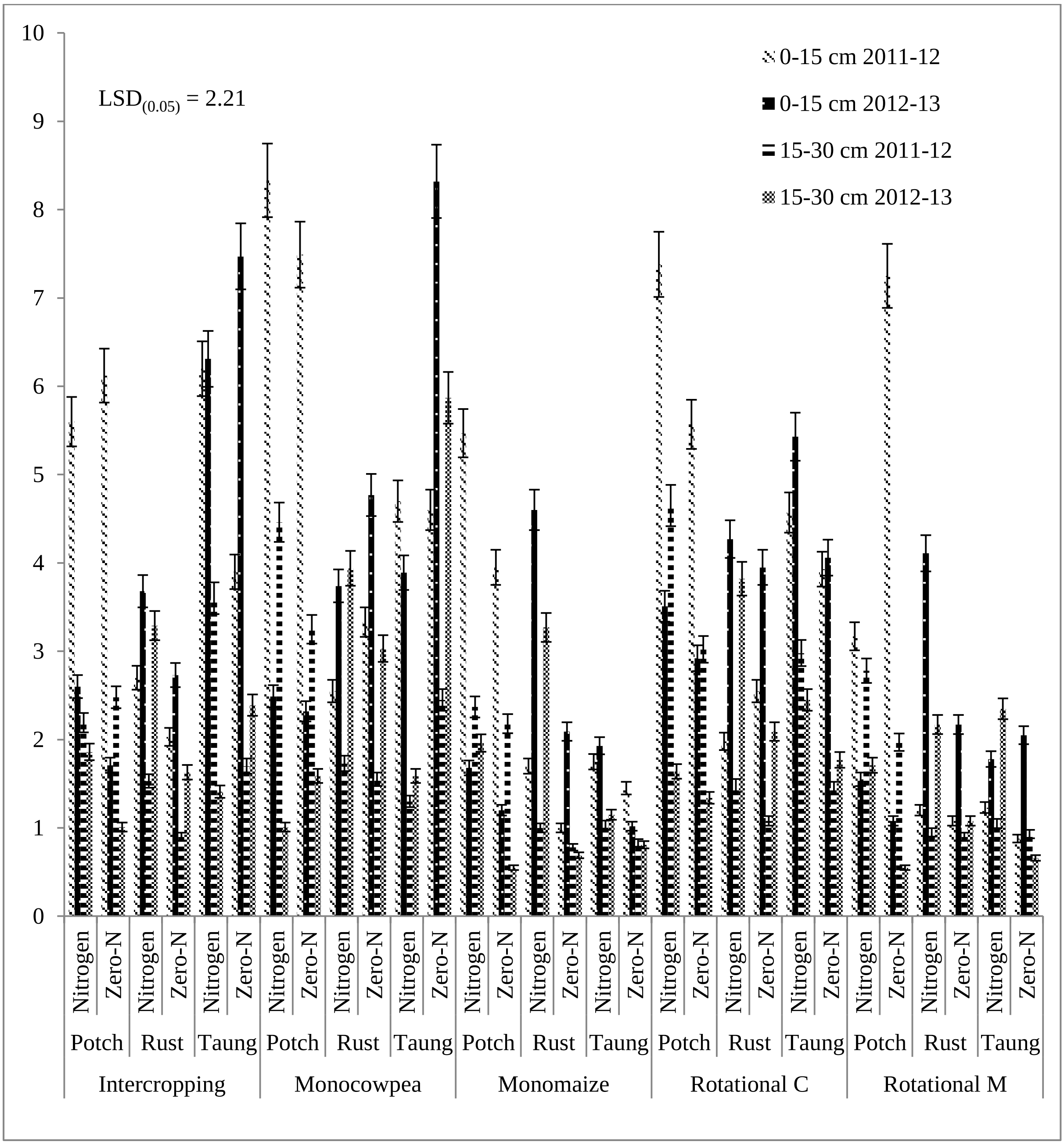
Figure 7.2. The interaction effects of cropping system, N fertilization, soil depth and site on soil Bray 1-P in mg kg^{-1}.



7.3.3. Soil nitrate (N-NO_3) content at harvest

Cropping system had significant effect ($P < 0.001$) on soil nitrate (Figure 7.3 and Appendix 7.1.C). Cowpea plots planted on intercropping, rotational and monocropping systems had significantly higher soil nitrate of 3.12, 3.24 and 3.68 mg kg^{-1} respectively than other cropping systems. Site had significant effect ($P < 0.001$) on soil nitrate. Soil collected at Potchefstroom and Taung had significantly ($P < 0.05$) higher soil nitrate of 3.10 and 2.83 mg kg^{-1} respectively than soil collected at Rustenburg. N fertilizer had also showed significant effect ($P = 0.008$) on soil nitrate. Plots applied with N fertilizer had significantly ($P < 0.05$) higher soil nitrate of 2.95 mg kg^{-1} than plots without N fertilizer application. Soil nitrate was significantly ($P < 0.05$) higher at the depth of 0-15 cm (3.55 mg kg^{-1}) than at the depth of 15-30 cm. The interaction of cropping system x site ($P < 0.001$) and cropping system x nitrogen ($P = 0.002$) had significantly affected soil nitrate. The interaction of cropping system x soil depth ($P = 0.004$); site x soil depth ($P = 0.010$) and site x season ($P < 0.001$) had significantly affected soil nitrate. The interaction of cropping system x site x nitrogen ($P = 0.045$); cropping system x nitrogen x season ($P = 0.012$) and site x nitrogen x season ($P = 0.004$) had significant role on soil nitrate. The interaction of site x soil depth x season ($P < 0.001$) had significantly affected soil nitrate.

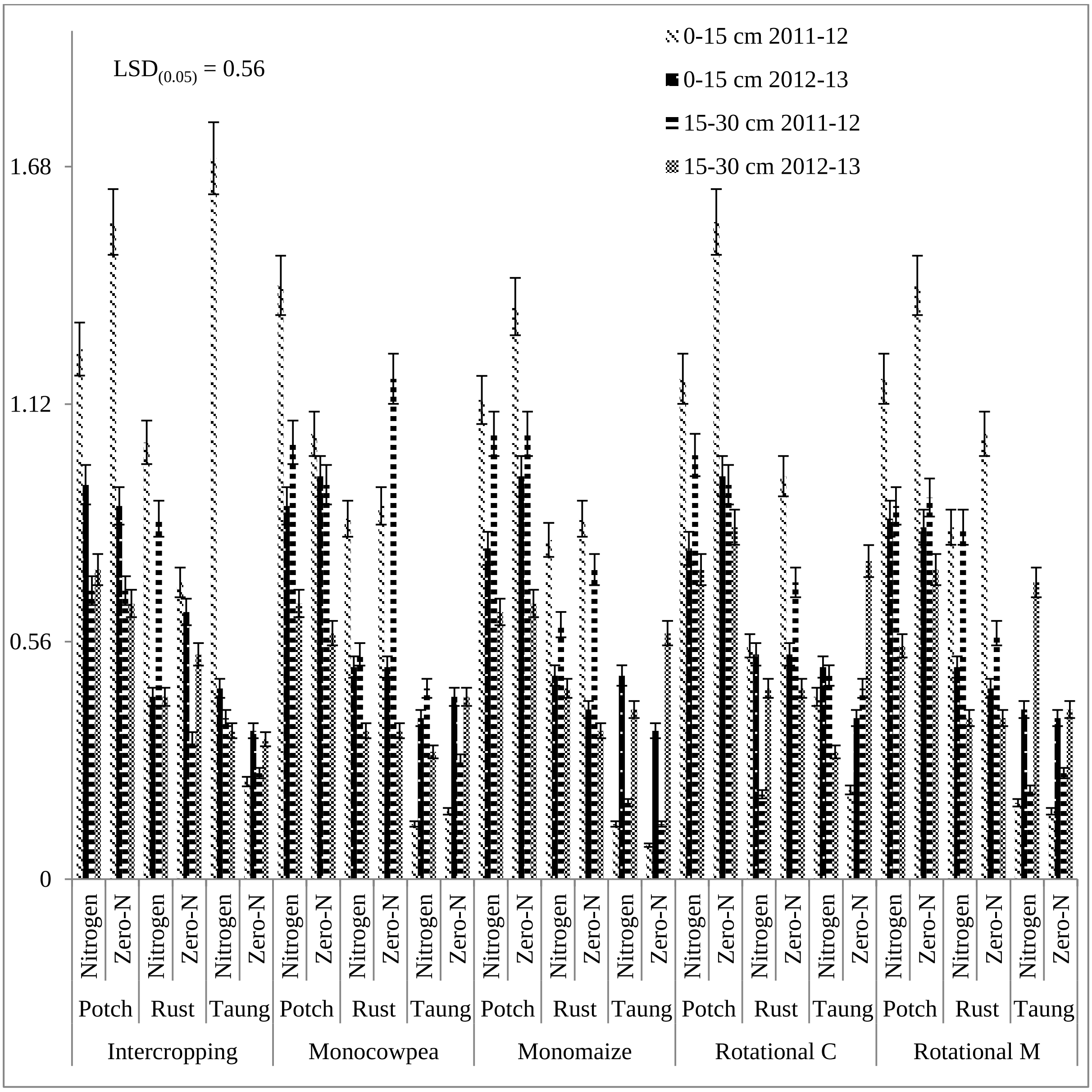
Figure 7.3. The interaction effects of cropping system, N fertilization, soil depth and site on soil N-NO_3 in mg kg^{-1}.



7.3.4. Soil ammonium (N-NH_4) content at harvest

Site had significant effect ($P < 0.001$) on soil ammonium (Figure 7.4 and Appendix 7.1.D). Soil collected at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher soil nitrate of 0.94 and 0.60 mg kg^{-1} respectively than soil collected at Taung. Soil ammonium was significantly ($P < 0.05$) higher at the depth of 0-15 cm (0.71 mg kg^{-1}) than at the depth of 15-130 cm. Season had significant effect ($P < 0.001$) on soil ammonium. Soil collected during 2011/12 planting season had significantly ($P < 0.05$) higher soil ammonium of 0.73 mg kg^{-1} than soil collected during 2012/13 planting season. The interaction of site x soil depth ($P = 0.004$) and site x season ($P < 0.001$) had significantly affected soil ammonium.

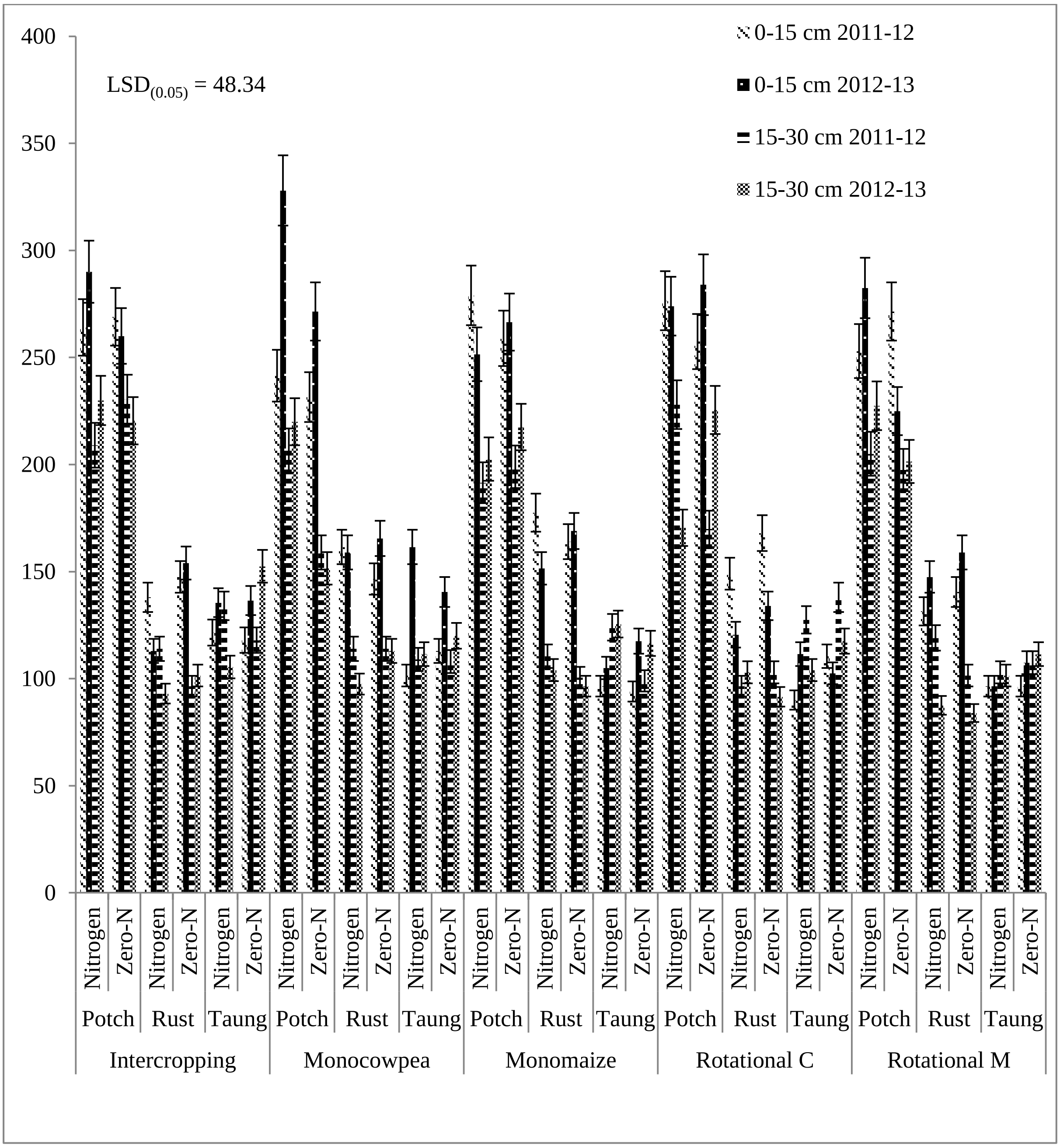
Figure 7.4. The interaction effects of cropping system, N fertilization, soil depth and site on soil N-NH_4 in mg kg^{-1}.



7.3.5. Soil exchangeable K content at harvest

Site had significant effect ($P < 0.001$) on exchangeable K (Figure 7.5 and Appendix 7.1.E). Soil collected at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher exchangeable K of 234.96 and 125.95 mg kg^{-1} respectively than soil collected at Taung. Soil depth had significant effect ($P < 0.001$) on exchangeable K. Soil exchangeable K was significantly ($P < 0.05$) higher on the depth of 0-15 cm (176.42 mg kg^{-1}) than at the depth of 15-30 cm. The interaction of site x soil depth ($P < 0.001$); site x season ($P = 0.045$) and the interaction of cropping system x site x nitrogen x season ($P = 0.038$) had significantly affected exchangeable K.

Figure 7.5. The interaction effects of cropping system, N fertilization, soil depth and site on soil exchangeable K in mg kg^{-1}.



7.4. Discussion

7.4.1. Soil organic carbon

The differences of soil organic carbon by sites corroborate the findings by Fu *et al.* (2004) who reported that soil organic carbon was affected by environmental factors such as topography, parent material, soil depth and land use. Topography influenced precipitation and temperature, both of which will affect the soil carbon (Tsui *et al.*, 2004). The differences in soil organic carbon by seasons may have been attributed to soil temperatures and rainfall. This supported the statement by Fang *et al.* (2008) who reported higher soil microbial biomass carbon in rainy season than in dry season. It was also revealed that soil carbon was significantly positively correlated with soil temperature. The higher soil organic carbon at Potchefstroom and Rustenburg may have been attributed to clay content on those sites. This confirmed statement by Oades (1988) that increasing clay content increases the size of soil carbon pool primarily through its stabilizing effect on soil carbon. The higher soil organic carbon in monocropping cowpea plots was due to improved soil structure and fertility, which led to high carbon content. This agreed with similar findings by Conant *et al.* (2001) who reported that introduction of legumes can increase soil nitrogen, resulting in superior soil fertility. Soil carbon increases was found to be generally greater with higher level of soil fertility. Alvarez (2005) reported that carbon sequestration increased as nitrogen fertilizer was applied to the system, and this contradicted the findings of this study. N fertilization had no effect on soil organic carbon. This corroborates the findings by Russell *et al.* (2009) who reported that N fertilization offset gains in carbon inputs to the soil in such a way that soil carbon sequestration was virtually nil despite up to 48 years of N addition.

7.4.2. Soil Bray 1-P

At Potchefstroom and Rustenburg, Bray 1-P was decreased in soil at the end of cropping as compared to P obtained before planting of trial (Table 7.1). This implied the high uptake of phosphorus during growth of both maize and cowpea. The amount of P (Bray-1) should be between the critical levels of 8-15 mg kg^{-1} (FSSA, 2003). The differences in soil P across the sites may have been attributed to different soil type of sites. This confirmed statements by Sharpley *et al*. (2004) that the processes behind P losses were complex and influenced by natural factors such as soil properties and weather condition. The coarse textured soil without macro pores, the direct risk of P leaching losses after application of P was generally low due to adsorption of P (Van Es *et al*., 2004). The high percentage of Bray 1-P in monocropping maize was not expected in this study. This study shows that it was possible to obtain high soil Bray 1-P content under sole maize as compared to sole cowpea. This could be attributed to high uptake of soil available phosphorus during vegetative and reproductive stage of cowpea crop. Hassan *et al*. (2012) reported that legumes had the ability to solubilise P from less pool in the soil. This corroborated with the findings of this study, where Bray 1-P was less in monocropping and rotational cowpea plots. It was also reported by Hassan *et al*. (2012) that including legume in rotation increases phosphorus availability to the following crop due to their deep roots. The differences in soil phosphorus across the seasons may have been attributed to poor drainage system that led to flooding.

7.4.3. Soil N-NO_3 and N-NH_4

The amount of N-NO_3 had increased at Potchefstroom and Taung at the end of cropping system as compared to N-NO_3 obtained before planting of trial (Table 7.1). The amount of N-NH_4 was decreased in soil at the end of cropping as compared to N-NH_4 obtained before planting at all sites. The differences of N-NO_3 and N-NH_4 across sites and seasons may have been attributed to different soil types, temperatures and rainfall. This confirmed statements by Zhou and Ouyang (2001) that there was the interactive effect of temperature and moisture on mineralization of soil nitrogen. Soil collected at Potchefstroom had higher N-NO_3 and N-NH_4, and this may have been attributed to high organic matter and soil texture of that soil, which reduced loss of nitrogen through leaching. This agreed with similar findings by Najmadeen *et al*. (2010) who reported the interactions among soil organic matter and total nitrogen contents with soil texture.

The amount of soil nitrate (N-NO_3) should be between the critical levels of 8-12 mg kg^{-1} (Fox and Valenzuela, 1989). At both 0-15 and 15-30 cm depths, N-NO_3 was below the critical level. The higher level of N-NO_3 in plots of cowpea planted under intercropping, monocropping and rotational systems may have been attributed to the improvement of soil structure and soil organic matter by cowpea. This agreed with similar findings by Rego and Seeling (1996) who reported that inclusion of grain legumes in rotation either as a sole crop or as an intercrop provided N-inputs into the system. The higher level of N-NO_3 in plots treated with N fertilizer agreed with similar findings by Raun *et al*. (1993) who reported that N fertilization significantly increased total soil N in the surface of 30 cm.

7.4.4. Soil exchangeable K

The amount of exchangeable K decreased at the end of cropping in Potchefstroom and Rustenburg as compared to the amount of exchangeable K obtained before cropping (Table 7.1). This indicated the high uptake of exchangeable K during cropping seasons by both cowpea and maize. The decrease in exchangeable K during the end of cropping was at Potchefstroom and Rustenburg where clay percentage was high. The amount of exchangeable K was increased in the end of cropping at Taung, where percentage of sand was high. This indicated the benefits of maize-cowpea rotation, intercropping and nitrogen fertilisation, by improving the amount of exchangeable K in sandy soil. Fox and Valenzuela (1989) reported that the critical levels of potassium (K) should be 40 mg kg^{-1}. The less content of exchangeable K in soil of Potchefstroom and Rustenburg at the end of cropping may have been attributed to high uptake of available K by crops. This confirmed the findings by Oldah (2011) who reported that when plant use K present in the soil solution, more K was released from the clay particles to the solution in response to decreased in concentration. The higher exchangeable K during 2012/13 planting season may have been attributed to the rate of rainfall, which had not led to severe leaching of K from surface soil. This confirmed statements by Shahbazi and Towfighi (2006) that exchangeable K decreased with increasing soil saturation. The interaction effect of cropping system x site x season on Bray 1-P, N-NO_3 and exchangeable K had contributed significantly towards the relevant of this study on soil structure improvement. In terms of site and season, Soriano-Soto *et al.* (1995) found that some soil properties improved at locations where higher amount of precipitation and lower temperature occurred.

7.5. Conclusions and recommendations

In this study, it has been shown that cropping system played a vital role on soil organic carbon and soil nitrate. Soil organic carbon and soil nitrate increased in cowpea plots planted on monocropping and rotational systems. These were more pronounced and statistically different across different sites. The inclusion of legume in cropping system improved soil organic carbon and total soil nitrogen. Soil chemical properties such as Bray 1-P, N-NO_3 and exchangeable K were affected significantly by the interaction of cropping system, site and season. Due to high precipitation and cooler temperatures at Potchefstroom, high organic carbon and chemical properties were expected. Application of nitrogen fertilizer had no effect on rise in soil organic carbon. In this study, it is recommended that, for the purpose of improving soil organic carbon and total soil nitrogen, cowpea should be included in cropping system as monocropping, rotation and intercropping with cereal crops. It is also recommended that, nitrogen fertilizer should be applied to soil for improvement of soil N-NO_3.

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CHAPTER 8

GENERAL DISCUSSION AND CONCLUSISONS

The findings in chapter 2 of higher soil moisture content at the depths of 0-15, 15-30, 30-60 and 60-90 cm before tasseling/flowering (V10/Vn) of maize-cowpea in Figures (2.1, 2.2, 2.3 and 2.4) may have been attributed to high crop canopy cover during that stage. This implies that evaporation from soil surface was reduced and led to high availability of soil moisture at soil root zone. This confirms the statements by Ghanbari *et al*. (2010) that water uptake from soil surface layers increased due to increased root density in the upper layers, thus decreasing water dissipated by evaporation. It is then assumed that, critical soil moisture requirements and high water uptake by crops is during VT/R4 stage.

During VT/R4 soil moisture content during analysis will be lower as compared to V10/Vn and R6/R8 stages. The interaction effects of growth stage x site x season on soil moisture content had significant contribution on moisture conservation, since such interactions appeared under 0-15, 15-30 and 60-90 cm depths. The stage before tasseling/flowering of maize-cowpea (V10/Vn) was found to have high moisture content. The critical stage for high soil water uptake by crops was at ear/pod formation stage (VT/R4) during the growth period of this study.

The findings in chapter 3 of early tasseling of maize applied with nitrogen fertilizer (Table 3.2) agrees with similar findings by Gajri *et al*. (1994) who reported that maize phenological parameters were significantly affected by the amount of nitrogen fertilizer. Cowpea-maize rotation was found to increase the growth of maize (Tables 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7) due to high improvement of soil structure by previous cowpea in the cropping system. Birch *et al*. (2003) reported that lower rates of growth and development processes and final leaf size occur at lower and higher temperatures and rainfall limitation. The longer ear length, higher ear mass, kernel number per ear and grain yield (Tables 3.8, 3.9 and Figures 3.1, 3.2) under rotational cropping system may have been attributed to the improved soil structure by previous cowpea. According to Carsky *et al*. (2001) cereal yield are almost always higher after a cowpea crop than after a cereal crop. Yield increase after cowpea compared with continuous cereal of the same species was 80% while it was only 31% for continuous cereal of differing species. The partial LER for maize in both planting season at three sites (Table 3.11) was higher as compared to cowpea, and this agrees with similar findings by Yilmaz *et al.* (2008) who reported that partial LER of cowpea decreased as the proportion of maize increased in mix-proportions.

The findings in chapter 4 reported cowpea planted on Monocropping and rotational systems to have reduced competition for resources such as sunlight and soil nutrients, and these resulted in earlier days to physiological maturity (Table 4.2). According to Amujoyegbe and Elemo (2013) site and time of introduction of cowpea affected growth of cowpea. The higher number of nodules per plant (Table 4.4) on cowpea planted at Taung may have been attributed to sandy soil type of the site. Dadson *et al*. (2003) reported that cowpea is a deep rooted crops and does well in sandy soils and more tolerant to drought than soybean.

The higher number of seeds per pods, pods mass, grain yield and field biomass (Table 4.6 and Figures 4.1, 4.2, 4.3) under cowpea planted on monocropping and rotational systems may have been attributed to improved soil structure and fertility by cowpea. This confirms the statements by Vesterager *et al*. (2007) that the N-value of growing cowpea monocropping was equivalent to the application of 50 kg N ha^{-1} as mineral fertilizer. The application of nitrogen fertilizer played a significant role on the growth of cowpea, but it did not affect the yield of cowpea. Intercropping of cowpea suppressed the growth and yield of cowpea.

The findings in chapter 5 in which cowpea leaf had higher protein (Figure 5.1) content under intercropping system might have been attributed to the shading by maize plants. The results confirm the statements by Musa *et al*. (2011) that intercropping increases the dry matter, ash, protein and fiber content of cowpea. The different of seed protein content (Figure 5.3) in different locations may have been attributed to different soil types. The previous study by Lauriault *et al*. (2011) indicated that protein content of cowpea did not differ among soil types of sites. In this study, the significant finding is that, cowpea crude protein differs by site due to different in soil fertility and structure. Intercropping has ability to increase the crude protein content in cowpea immature leaves. Application of nitrogen fertilizer to cowpea contributed to higher protein content of immature pods (Figure 5.2).

In Chapter 6, maize seed oil content (Figure 6.1) was affected by the interaction effect of cropping system x site x nitrogen x season. The study conducted by Riedell *et al*. (2009) indicated that year had no significant effect on kernel oil concentration and there were no significant N input x rotation interactions for kernel oil concentration in their study. The higher seed protein (Figure 6.2) content under plots applied with nitrogen fertilizer corroborates the findings by Da Silva *et al*. (2005), who reported that nitrogen application at silking also increases kernel crude protein content up to the application of 100 kg N ha^{-1}.

The starch content of maize grains (Figure 6.3) in this study differed across the seasons and this corroborates the findings by Buresova *et al*. (2010) who reported that starch content was significantly affected by weather during growing season. The higher seed phosphorus content (Figure 6.4) under intercropping system agrees with similar findings by Biareh *et al*. (2013) who revealed that intercropping culture had significant effect on phosphorus content. The high phosphorus content of maize seed under N-fertilizer treated plots may have been attributed to increased uptake of N by maize. The influence of nitrogen fertilizer on maize seed phosphorus content was also reported by Tarighaleslami *et al*. (2013), that different level of nitrogen fertilizer treatments had significant effect on phosphorus of seed and maximum phosphorus of seeds was gained by utilization of 180 kg ha^{-1} of nitrogen fertilizers. Maize seeds collected at site with high clay soil content (Potchefstroom and Rustenburg) had high oil and starch content as compared to site with high sand. The application of nitrogen fertilizer increases maize seed protein and phosphorus content.

Chapter 7 of this study indicates the differences of soil organic carbon (Figure 7.1) by sites which corroborate the findings by Fu *et al*. (2004) who reported that soil organic carbon is affected by environmental factors such as topography, parent material, soil depth and land use. The higher soil organic carbon in monocropping cowpea plots was due to improved soil structure and fertility, which led to high carbon content. This agrees with similar findings by Conant *et al*. (2001) who reported that introduction of legumes can increase soil nitrogen, resulting in superior soil fertility.

The differences in soil Bray 1-P (Figure 7.2) across the sites may have been attributed to different soil type of sites. This confirms statements by Sharpley *et al*. (2004) that the processes behind P losses are complex and influenced by natural factors such as soil properties and weather condition. Soil collected at Potchefstroom had higher $N\text{-}NO_3$ and $N\text{-}NH_4$ (Figures 7.3 and 7.4), and this may have been attributed to high organic matter and soil texture of that soil, which reduced loss of nitrogen through leaching.

This agrees with similar findings by Najmadeen *et al*. (2010) who reported the interactions among soil organic matter and total nitrogen contents with soil texture. The less content of exchangeable K (Figure 7.5) in soil of Potchefstroom and Rustenburg at the end of cropping may have been attributed to high uptake of available K by crops. This confirms the findings by Oldah (2011) who reported that when plant use K present in the soil solution, more K is released from the clay particles to the solution in response to decrease in concentration. Soil organic carbon and soil nitrate increases in cowpea plots planted on monocropping and rotational systems. The inclusion of legume in cropping system improves soil organic carbon and total soil nitrogen.

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APPENDICES

Appendix 2.1. Analysis of variance of soil moisture content at three locations during 2011/12 and 2012/13 planting seasons.

A. Soil depth of 0-15 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	153.201	76.600	42.31	
Rep.*Units* stratum					
Cropping system (CS)	4	9.432	2.358	1.30	0.269
Growth stage (GS)	2	214.971	107.486	59.36	<.001
Location (LN)	2	8197.833	4098.917	2263.82	<.001
Nitrogen (N)	1	4.619	4.619	2.55	0.111
Season (SN)	1	187.903	187.903	103.78	<.001
CS.GS	8	25.086	3.136	1.73	0.090
CS.LN	8	16.575	2.072	1.14	0.333
GS.LN	4	330.573	82.643	45.64	<.001
CS.N	4	4.782	1.196	0.66	0.620
GS.N	2	0.160	0.080	0.04	0.957
LN.N	2	3.025	1.512	0.84	0.435
CS.SN	4	8.291	2.073	1.14	0.335
GS.SN	2	104.685	52.342	28.91	<.001
LN.SN	2	487.790	243.895	134.70	<.001
N.SN	1	4.977	4.977	2.75	0.098
CS.GS.LN	16	29.487	1.843	1.02	0.437
CS.GS.N	8	12.521	1.565	0.86	0.547
CS.LN.N	8	10.602	1.325	0.73	0.663
GS.LN.N	4	13.927	3.482	1.92	0.106
CS.GS.SN	8	9.591	1.199	0.66	0.725
CS.LN.SN	8	10.128	1.266	0.70	0.692
GS.LN.SN	4	177.626	44.407	24.53	<.001
CS.N.SN	4	2.661	0.665	0.37	0.832
GS.N.SN	2	0.804	0.402	0.22	0.801
LN.N.SN	2	0.785	0.392	0.22	0.805
CS.GS.LN.N	16	36.971	2.311	1.28	0.209
CS.GS.LN.SN	16	18.817	1.176	0.65	0.842
CS.GS.N.SN	8	7.999	1.000	0.55	0.817
CS.LN.N.SN	8	6.763	0.845	0.47	0.879
GS.LN.N.SN	4	5.575	1.394	0.77	0.545
CS.GS.LN.N.SN	16	16.665	1.042	0.58	0.902
Residual	358	648.201	1.811		
Total	539	10763.025			

B. Soil depth of 15-30 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	186.327	93.164	42.12	
Rep.*Units* stratum					
Cropping system (CS)	4	19.237	4.809	2.17	0.071
Growth stage (GS)	2	84.501	42.251	19.10	<.001
Location (LN)	2	11331.994	5665.997	2561.94	<.001
Nitrogen (N)	1	6.754	6.754	3.05	0.081
Season (SN)	1	0.004	0.004	0.00	0.966
CS.GS	8	18.589	2.324	1.05	0.398
CS.LN	8	36.051	4.506	2.04	0.041
GS.LN	4	115.921	28.980	13.10	<.001
CS.N	4	14.651	3.663	1.66	0.160
GS.N	2	0.695	0.347	0.16	0.855
LN.N	2	1.148	0.574	0.26	0.772
CS.SN	4	2.066	0.517	0.23	0.919
GS.SN	2	87.337	43.668	19.75	<.001
LN.SN	2	76.444	38.222	17.28	<.001
N.SN	1	1.783	1.783	0.81	0.370
CS.GS.LN	16	21.436	1.340	0.61	0.879
CS.GS.N	8	12.441	1.555	0.70	0.689
CS.LN.N	8	15.817	1.977	0.89	0.522
GS.LN.N	4	12.098	3.025	1.37	0.245
CS.GS.SN	8	4.765	0.596	0.27	0.976
CS.LN.SN	8	33.613	4.202	1.90	0.059
GS.LN.SN	4	69.016	17.254	7.80	<.001
CS.N.SN	4	11.173	2.793	1.26	0.284
GS.N.SN	2	2.625	1.312	0.59	0.553
LN.N.SN	2	4.775	2.387	1.08	0.341
CS.GS.LN.N	16	25.983	1.624	0.73	0.759
CS.GS.LN.SN	16	31.363	1.960	0.89	0.586
CS.GS.N.SN	8	9.704	1.213	0.55	0.820
CS.LN.N.SN	8	11.801	1.475	0.67	0.721
GS.LN.N.SN	4	3.772	0.943	0.43	0.790
CS.GS.LN.N.SN	16	20.105	1.257	0.57	0.907
Residual	358	791.753	2.212		
Total	539	13065.742			

C. Soil depth of 30-60 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	223.838	111.919	54.55	
Rep.*Units* stratum					
Cropping system (CS)	4	22.484	5.621	2.74	0.029
Growth stage (GS)	2	88.377	44.188	21.54	<.001
Location (LN)	2	16534.888	8267.444	4029.69	<.001
Nitrogen (N)	1	2.522	2.522	1.23	0.268
Season (SN)	1	55.258	55.258	26.93	<.001
CS.GS	8	21.505	2.688	1.31	0.237
CS.LN	8	41.619	5.202	2.54	0.011
GS.LN	4	31.905	7.976	3.89	0.004
CS.N	4	9.897	2.474	1.21	0.308
GS.N	2	4.012	2.006	0.98	0.377
LN.N	2	1.229	0.614	0.30	0.741
CS.SN	4	6.343	1.586	0.77	0.543
GS.SN	2	28.634	14.317	6.98	0.001
LN.SN	2	74.863	37.432	18.24	<.001
N.SN	1	1.475	1.475	0.72	0.397
CS.GS.LN	16	32.868	2.054	1.00	0.455
CS.GS.N	8	8.513	1.064	0.52	0.842
CS.LN.N	8	43.453	5.432	2.65	0.008
GS.LN.N	4	6.907	1.727	0.84	0.499
CS.GS.SN	8	13.126	1.641	0.80	0.603
CS.LN.SN	8	39.888	4.986	2.43	0.014
GS.LN.SN	4	5.760	1.440	0.70	0.591
CS.N.SN	4	5.577	1.394	0.68	0.607
GS.N.SN	2	4.719	2.360	1.15	0.318
LN.N.SN	2	1.597	0.798	0.39	0.678
CS.GS.LN.N	16	25.925	1.620	0.79	0.697
CS.GS.LN.SN	16	23.893	1.493	0.73	0.766
CS.GS.N.SN	8	24.544	3.068	1.50	0.157
CS.LN.N.SN	8	32.134	4.017	1.96	0.051
GS.LN.N.SN	4	4.596	1.149	0.56	0.692
CS.GS.LN.N.SN	16	25.210	1.576	0.77	0.722
Residual	358	734.485	2.052		
Total	539	18182.041			

D. Soil depth of 60-90 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	159.723	79.862	39.23	
Rep.*Units* stratum					
Cropping system (CS)	4	7.877	1.969	0.97	0.425
Growth stage (GS)	2	127.244	63.622	31.26	<.001
Location (LN)	2	18115.519	9057.759	4449.81	<.001
Nitrogen (N)	1	0.624	0.624	0.31	0.580
Season (SN)	1	134.151	134.151	65.90	<.001
CS.GS	8	39.571	4.946	2.43	0.014
CS.LN	8	14.297	1.787	0.88	0.535
GS.LN	4	64.356	16.089	7.90	<.001
CS.N	4	7.667	1.917	0.94	0.440
GS.N	2	1.161	0.580	0.29	0.752
LN.N	2	5.592	2.796	1.37	0.255
CS.SN	4	4.479	1.120	0.55	0.699
GS.SN	2	34.644	17.322	8.51	<.001
LN.SN	2	93.141	46.570	22.88	<.001
N.SN	1	3.359	3.359	1.65	0.200
CS.GS.LN	16	19.806	1.238	0.61	0.878
CS.GS.N	8	5.382	0.673	0.33	0.954
CS.LN.N	8	18.797	2.350	1.15	0.326
GS.LN.N	4	2.568	0.642	0.32	0.868
CS.GS.SN	8	23.057	2.882	1.42	0.188
CS.LN.SN	8	11.554	1.444	0.71	0.683
GS.LN.SN	4	21.436	5.359	2.63	0.034
CS.N.SN	4	14.171	3.543	1.74	0.141
GS.N.SN	2	3.754	1.877	0.92	0.399
LN.N.SN	2	0.400	0.200	0.10	0.906
CS.GS.LN.N	16	21.626	1.352	0.66	0.829
CS.GS.LN.SN	16	8.287	0.518	0.25	0.999
CS.GS.N.SN	8	7.996	0.999	0.49	0.863
CS.LN.N.SN	8	21.798	2.725	1.34	0.223
GS.LN.N.SN	4	8.246	2.062	1.01	0.401
CS.GS.LN.N.SN	16	17.977	1.124	0.55	0.918
Residual	358	728.722	2.036		
Total	539	19748.978			

Appendix 3.1. Analysis of variance of maize growth and yield parameters at three locations during 2011/12 and 2012/13 planting seasons.

A. Days to 100% tasseling of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4.39	2.19	0.20	
Rep.*Units* stratum					
Cropping system (CS)	2	126.00	63.00	5.70	0.005
Location (LC)	2	2952.06	1476.03	133.44	<.001
Nitrogen (N)	1	1386.75	1386.75	125.37	<.001
Season (SN)	1	444.08	444.08	40.15	<.001
CS.LC	4	22.11	5.53	0.50	0.736
CS.N	2	20.22	10.11	0.91	0.406
LC.N	2	387.06	193.53	17.50	<.001
CS.SN	2	8.22	4.11	0.37	0.691
LC.SN	2	229.06	114.53	10.35	<.001
N.SN	1	34.45	34.45	3.11	0.082
CS.LC.N	4	33.89	8.47	0.77	0.551
CS.LC.SN	4	102.89	25.72	2.33	0.065
CS.N.SN	2	4.96	2.48	0.22	0.800
LC.N.SN	2	32.35	16.18	1.46	0.239
CS.LC.N.SN	4	36.15	9.04	0.82	0.519
Residual	70	774.28	11.06		
Total	107	6598.92			

B. Days to physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	13.352	6.676	1.69	
Rep.*Units* stratum					
Cropping system (CS)	2	105.241	52.620	13.31	<.001
Location (LC)	2	42898.130	21449.065	5427.24	<.001
Nitrogen (N)	1	197.370	197.370	49.94	<.001
Season (SN)	1	4107.000	4107.000	1039.19	<.001
CS.LC	4	69.537	17.384	4.40	0.003
CS.N	2	29.019	14.509	3.67	0.030
LC.N	2	1567.796	783.898	198.35	<.001
CS.SN	2	6.167	3.083	0.78	0.462
LC.SN	2	513.722	256.861	64.99	<.001
N.SN	1	7.259	7.259	1.84	0.180
CS.LC.N	4	5.648	1.412	0.36	0.838
CS.LC.SN	4	19.278	4.819	1.22	0.310
CS.N.SN	2	72.463	36.231	9.17	<.001
LC.N.SN	2	59.241	29.620	7.49	0.001
CS.LC.N.SN	4	43.537	10.884	2.75	0.035
Residual	70	276.648	3.952		
Total	107	49991.407			

C. Maize leaf area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	168498.	84249.	9.06	
Rep.*Units* stratum					
Cropping system (CS)	2	124898.	62449.	6.71	0.002
Location (LC)	2	2588989.	1294495.	139.14	<.001
Nitrogen (N)	1	1486590.	1486590.	159.79	<.001
Season (SN)	1	353279.	353279.	37.97	<.001
CS.LC	4	55164.	13791.	1.48	0.217
CS.N	2	27358.	13679.	1.47	0.237
LC.N	2	44757.	22378.	2.41	0.098
CS.SN	2	130119.	65059.	6.99	0.002
LC.SN	2	18216.	9108.	0.98	0.381
N.SN	1	4841.	4841.	0.52	0.473
CS.LC.N	4	104419.	26105.	2.81	0.032
CS.LC.SN	4	55610.	13902.	1.49	0.213
CS.N.SN	2	23360.	11680.	1.26	0.291
LC.N.SN	2	7773.	3886.	0.42	0.660
CS.LC.N.SN	4	32230.	8058.	0.87	0.489
Residual	70	651256.	9304.		
Total	107	5877357.			

D. Number of leaves per maize plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4.317	2.158	1.52	
Rep.*Units* stratum					
Cropping system (CS)	2	6.588	3.294	2.32	0.105
Location (LC)	2	103.836	51.918	36.63	<.001
Nitrogen (N)	1	3.203	3.203	2.26	0.137
Season (SN)	1	1.517	1.517	1.07	0.304
CS.LC	4	7.103	1.776	1.25	0.297
CS.N	2	1.185	0.593	0.42	0.660
LC.N	2	10.502	5.251	3.70	0.030
CS.SN	2	0.652	0.326	0.23	0.795
LC.SN	2	41.671	20.836	14.70	<.001
N.SN	1	0.006	0.006	0.00	0.949
CS.LC.N	4	2.457	0.614	0.43	0.784
CS.LC.SN	4	1.676	0.419	0.30	0.880
CS.N.SN	2	1.650	0.825	0.58	0.561
LC.N.SN	2	4.940	2.470	1.74	0.183
CS.LC.N.SN	4	3.320	0.830	0.59	0.674
Residual	70	99.223	1.417		
Total	107	293.846			

E. Maize plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4907.8	2453.9	7.85	
Rep.*Units* stratum					
Cropping system (CS)	2	6583.7	3291.8	10.53	<.001
Location (LC)	2	30127.8	15063.9	48.20	<.001
Nitrogen (N)	1	9716.6	9716.6	31.09	<.001
Season (SN)	1	21308.2	21308.2	68.17	<.001
CS.LC	4	1360.5	340.1	1.09	0.369
CS.N	2	1097.6	548.8	1.76	0.180
LC.N	2	468.2	234.1	0.75	0.477
CS.SN	2	1028.9	514.5	1.65	0.200
LC.SN	2	11646.1	5823.1	18.63	<.001
N.SN	1	1437.4	1437.4	4.60	0.035
CS.LC.N	4	1332.2	333.1	1.07	0.380
CS.LC.SN	4	642.4	160.6	0.51	0.726
CS.N.SN	2	37.8	18.9	0.06	0.941
LC.N.SN	2	16.6	8.3	0.03	0.974
CS.LC.N.SN	4	285.6	71.4	0.23	0.922
Residual	70	21879.1	312.6		
Total	107	113876.7			

F. Maize stem diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.51185	0.25593	5.45	
Rep.*Units* stratum					
Cropping system (CS)	2	0.25907	0.12954	2.76	0.070
Location (LC)	2	4.88130	2.44065	51.96	<.001
Nitrogen (N)	1	5.92676	5.92676	126.17	<.001
Season (SN)	1	1.89343	1.89343	40.31	<.001
CS.LC	4	0.08204	0.02051	0.44	0.782
CS.N	2	0.08907	0.04454	0.95	0.392
LC.N	2	0.78907	0.39454	8.40	<.001
CS.SN	2	0.38685	0.19343	4.12	0.020
LC.SN	2	0.14685	0.07343	1.56	0.217
N.SN	1	0.00750	0.00750	0.16	0.691
CS.LC.N	4	0.36426	0.09106	1.94	0.114
CS.LC.SN	4	0.11870	0.02968	0.63	0.641
CS.N.SN	2	0.03389	0.01694	0.36	0.698
LC.N.SN	2	0.05167	0.02583	0.55	0.579
CS.LC.N.SN	4	0.04611	0.01153	0.25	0.912
Residual	70	3.28815	0.04697		
Total	107	18.87657			

G. Maize ear length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	25.179	12.589	4.04	
Rep.*Units* stratum					
Cropping system (CS)	2	19.635	9.817	3.15	0.049
Location (LN)	2	82.921	41.460	13.31	<.001
Nitrogen (N)	1	161.089	161.089	51.71	<.001
Season (SN)	1	18.008	18.008	5.78	0.019
CS.LN	4	12.179	3.045	0.98	0.426
CS.N	2	13.789	6.895	2.21	0.117
LN.N	2	9.250	4.625	1.48	0.234
CS.SN	2	16.752	8.376	2.69	0.075
LN.SN	2	27.082	13.541	4.35	0.017
N.SN	1	6.405	6.405	2.06	0.156
CS.LN.N	4	27.401	6.850	2.20	0.078
CS.LN.SN	4	5.311	1.328	0.43	0.789
CS.N.SN	2	6.322	3.161	1.01	0.368
LN.N.SN	2	18.387	9.194	2.95	0.059
CS.LN.N.SN	4	16.255	4.064	1.30	0.277
Residual	70	218.081	3.115		
Total	107	684.045			

H. Maize ear mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	19711433.	9855716.	8.12	
Rep.*Units* stratum					
Cropping system (CS)	2	71547572.	35773786.	29.48	<.001
Location (LN)	2	101568977.	50784488.	41.85	<.001
Nitrogen (N)	1	41937247.	41937247.	34.56	<.001
Season (SN)	1	56671695.	56671695.	46.70	<.001
CS.LN	4	27112093.	6778023.	5.59	<.001
CS.N	2	8018827.	4009413.	3.30	0.043
LN.N	2	2129452.	1064726.	0.88	0.420
CS.SN	2	3826765.	1913383.	1.58	0.214
LN.SN	2	1070223.	535112.	0.44	0.645
N.SN	1	220784.	220784.	0.18	0.671
CS.LN.N	4	15743482.	3935871.	3.24	0.017
CS.LN.SN	4	10659361.	2664840.	2.20	0.078
CS.N.SN	2	894253.	447127.	0.37	0.693
LN.N.SN	2	1851790.	925895.	0.76	0.470
CS.LN.N.SN	4	3441511.	860378.	0.71	0.588
Residual	70	84945870.	1213512.		
Total	107	451351336.			

I. Maize kernel number per ear

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	11941.	5970.	1.24	
Rep.*Units* stratum					
Cropping system (CS)	2	42552.	21276.	4.40	0.016
Location (LN)	2	109530.	54765.	11.33	<.001
Nitrogen (N)	1	191690.	191690.	39.67	<.001
Season (SN)	1	23639.	23639.	4.89	0.030
CS.LN	4	17242.	4311.	0.89	0.473
CS.N	2	1390.	695.	0.14	0.866
LN.N	2	20292.	10146.	2.10	0.130
CS.SN	2	16154.	8077.	1.67	0.195
LN.SN	2	34273.	17136.	3.55	0.034
N.SN	1	7487.	7487.	1.55	0.217
CS.LN.N	4	22637.	5659.	1.17	0.331
CS.LN.SN	4	18836.	4709.	0.97	0.427
CS.N.SN	2	19744.	9872.	2.04	0.137
LN.N.SN	2	9175.	4587.	0.95	0.392
CS.LN.N.SN	4	2809.	702.	0.15	0.964
Residual	70	338244.	4832.		
Total	107	887632.			

J. Maize hundred seed mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	9.436	4.718	1.95	
Rep.*Units* stratum					
Cropping system (CS)	2	11.312	5.656	2.33	0.105
Location (LN)	2	25.685	12.843	5.29	0.007
Nitrogen (N)	1	110.616	110.616	45.61	<.001
Season (SN)	1	636.078	636.078	262.25	<.001
CS.LN	4	11.615	2.904	1.20	0.320
CS.N	2	10.125	5.062	2.09	0.132
LN.N	2	48.579	24.289	10.01	<.001
CS.SN	2	1.500	0.750	0.31	0.735
LN.SN	2	129.970	64.985	26.79	<.001
N.SN	1	14.447	14.447	5.96	0.017
CS.LN.N	4	24.214	6.053	2.50	0.051
CS.LN.SN	4	4.805	1.201	0.50	0.739
CS.N.SN	2	0.190	0.095	0.04	0.962
LN.N.SN	2	15.087	7.544	3.11	0.051
CS.LN.N.SN	4	3.128	0.782	0.32	0.862
Residual	70	169.784	2.425		
Total	107	1226.570			

K. Maize grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	12046419.	6023209.	7.12	
Rep.*Units* stratum					
Cropping system (CS)	2	48030924.	24015462.	28.38	<.001
Location (LN)	2	54533634.	27266817.	32.22	<.001
Nitrogen (N)	1	28658722.	28658722.	33.86	<.001
Season (SN)	1	41213438.	41213438.	48.70	<.001
CS.LN	4	18274075.	4568519.	5.40	<.001
CS.N	2	4545178.	2272589.	2.69	0.075
LN.N	2	1062882.	531441.	0.63	0.537
CS.SN	2	2281334.	1140667.	1.35	0.266
LN.SN	2	800606.	400303.	0.47	0.625
N.SN	1	198764.	198764.	0.23	0.629
CS.LN.N	4	10377646.	2594411.	3.07	0.022
CS.LN.SN	4	6460473.	1615118.	1.91	0.119
CS.N.SN	2	588760.	294380.	0.35	0.707
LN.N.SN	2	1378617.	689308.	0.81	0.447
CS.LN.N.SN	4	2013710.	503427.	0.59	0.668
Residual	70	59241460.	846307.		
Total	107	291706642.			

L. Maize plant population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4.008E+08	2.004E+08	6.16	
Rep.*Units* stratum					
Cropping system (CS)	2	5.922E+08	2.961E+08	9.11	<.001
Location (LN)	2	1.517E+09	7.586E+08	23.33	<.001
Nitrogen (N)	1	1.725E+09	1.725E+09	53.06	<.001
Season (SN)	1	6.667E+08	6.667E+08	20.50	<.001
CS.LN	4	2.340E+08	5.849E+07	1.80	0.139
CS.N	2	7.362E+07	3.681E+07	1.13	0.328
LN.N	2	2.822E+08	1.411E+08	4.34	0.017
CS.SN	2	2.548E+07	1.274E+07	0.39	0.677
LN.SN	2	7.303E+08	3.652E+08	11.23	<.001
N.SN	1	8.652E+07	8.652E+07	2.66	0.107
CS.LN.N	4	3.052E+08	7.630E+07	2.35	0.063
CS.LN.SN	4	1.798E+08	4.495E+07	1.38	0.249
CS.N.SN	2	5.719E+07	2.859E+07	0.88	0.420
LN.N.SN	2	5.733E+08	2.867E+08	8.82	<.001
CS.LN.N.SN	4	1.459E+08	3.648E+07	1.12	0.353
Residual	70	2.276E+09	3.251E+07		
Total	107	9.872E+09			

M. Maize stover yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	6.255E+07	3.127E+07	2.79	
Rep.*Units* stratum					
Cropping system (CS)	2	1.641E+08	8.205E+07	7.33	0.001
Location (LN)	2	4.874E+08	2.437E+08	21.77	<.001
Nitrogen (N)	1	2.396E+07	2.396E+07	2.14	0.148
Season (SN)	1	1.377E+09	1.377E+09	123.05	<.001
CS.LN	4	6.863E+07	1.716E+07	1.53	0.202
CS.N	2	2.906E+07	1.453E+07	1.30	0.280
LN.N	2	1.572E+08	7.862E+07	7.02	0.002
CS.SN	2	5.937E+07	2.968E+07	2.65	0.078
LN.SN	2	3.595E+08	1.797E+08	16.06	<.001
N.SN	1	2.860E+05	2.860E+05	0.03	0.873
CS.LN.N	4	5.583E+07	1.396E+07	1.25	0.299
CS.LN.SN	4	4.602E+07	1.151E+07	1.03	0.399
CS.N.SN	2	2.458E+06	1.229E+06	0.11	0.896
LN.N.SN	2	2.167E+08	1.084E+08	9.68	<.001
CS.LN.N.SN	4	1.509E+07	3.772E+06	0.34	0.852
Residual	70	7.836E+08	1.119E+07		
Total	107	3.909E+09			

Appendix 4.1. Analysis of variance of cowpea growth and yield parameters at three locations during 2011/12 and 2012/13 planting seasons.

A. Days to 100% flowering of cowpea

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	9.500	4.750	1.32	
Rep.*Units* stratum					
Cropping system (CS)	2	73.500	36.750	10.22	<.001
Nitrogen (N)	1	773.343	773.343	214.96	<.001
Location (LC)	2	2051.056	1025.528	285.06	<.001
Season (SN)	1	18.750	18.750	5.21	0.025
CS.N	2	25.796	12.898	3.59	0.033
CS.LC	4	58.111	14.528	4.04	0.005
N.LC	2	129.241	64.620	17.96	<.001
CS.SN	2	0.722	0.361	0.10	0.905
N.SN	1	34.454	34.454	9.58	0.003
LC.SN	2	1643.056	821.528	228.35	<.001
CS.N.LC	4	23.704	5.926	1.65	0.172
CS.N.SN	2	0.130	0.065	0.02	0.982
CS.LC.SN	4	36.556	9.139	2.54	0.047
N.LC.SN	2	12.574	6.287	1.75	0.182
CS.N.LC.SN	4	3.926	0.981	0.27	0.895
Residual	70	251.833	3.598		
Total	107	5146.250			

B. Days to physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.1667	1.0833	1.13	
Rep.*Units* stratum					
Cropping system (CS)	2	651.1667	325.5833	339.32	<.001
Nitrogen (N)	1	1008.3333	1008.3333	1050.87	<.001
Location (LC)	2	11148.7222	5574.3611	5809.51	<.001
Season (SN)	1	8251.2593	8251.2593	8599.33	<.001
CS.N	2	77.7222	38.8611	40.50	<.001
CS.LC	4	39.6111	9.9028	10.32	<.001
N.LC	2	36.1667	18.0833	18.85	<.001
CS.SN	2	447.7963	223.8981	233.34	<.001
N.SN	1	88.9259	88.9259	92.68	<.001
LC.SN	2	412.3519	206.1759	214.87	<.001
CS.N.LC	4	18.9444	4.7361	4.94	0.001
CS.N.SN	2	2.5741	1.2870	1.34	0.268
CS.LC.SN	4	77.7593	19.4398	20.26	<.001
N.LC.SN	2	46.6852	23.3426	24.33	<.001
CS.N.LC.SN	4	4.6481	1.1620	1.21	0.314
Residual	70	67.1667	0.9595		
Total	107	22382.0000			

C. Number of leaves per cowpea plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	64.4	32.2	0.24	
Rep.*Units* stratum					
Cropping system (CS)	2	2441.4	1220.7	9.21	<.001
Nitrogen (N)	1	197.4	197.4	1.49	0.227
Location (LC)	2	660.9	330.4	2.49	0.090
Season (SN)	1	4.3	4.3	0.03	0.857
CS.N	2	301.4	150.7	1.14	0.327
CS.LC	4	260.6	65.1	0.49	0.742
N.LC	2	378.1	189.1	1.43	0.247
CS.SN	2	114.8	57.4	0.43	0.650
N.SN	1	27.6	27.6	0.21	0.650
LC.SN	2	2930.6	1465.3	11.05	<.001
CS.N.LC	4	335.5	83.9	0.63	0.641
CS.N.SN	2	280.4	140.2	1.06	0.353
CS.LC.SN	4	67.3	16.8	0.13	0.972
N.LC.SN	2	143.9	71.9	0.54	0.584
CS.N.LC.SN	4	686.6	171.7	1.29	0.280
Residual	70	9280.1	132.6		
Total	107	18175.2			

D. Number of nodules per cowpea plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	7.065	3.533	0.37	
Rep.*Units* stratum					
Cropping system (CS)	2	16.857	8.429	0.87	0.422
Nitrogen (N)	1	23.989	23.989	2.48	0.120
Location (LC)	2	858.382	429.191	44.45	<.001
Season (SN)	1	1690.605	1690.605	175.07	<.001
CS.N	2	24.106	12.053	1.25	0.293
CS.LC	4	51.791	12.948	1.34	0.263
N.LC	2	84.045	42.022	4.35	0.017
CS.SN	2	11.864	5.932	0.61	0.544
N.SN	1	23.056	23.056	2.39	0.127
LC.SN	2	153.857	76.928	7.97	<.001
CS.N.LC	4	105.615	26.404	2.73	0.036
CS.N.SN	2	1.254	0.627	0.06	0.937
CS.LC.SN	4	45.413	11.353	1.18	0.329
N.LC.SN	2	28.770	14.385	1.49	0.233
CS.N.LC.SN	4	50.161	12.540	1.30	0.279
Residual	70	675.962	9.657		
Total	107	3852.789			

E. Cowpea pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.2702	0.6351	1.36	
Rep.*Units* stratum					
Cropping system (CS)	2	2.5302	1.2651	2.71	0.074
Location (LN)	2	15.7480	7.8740	16.84	<.001
Nitrogen (N)	1	0.4033	0.4033	0.86	0.356
Season (SN)	1	0.0448	0.0448	0.10	0.758
CS.LN	4	0.9259	0.2315	0.50	0.739
CS.N	2	3.3050	1.6525	3.53	0.034
LN.N	2	2.3439	1.1719	2.51	0.089
CS.SN	2	1.7646	0.8823	1.89	0.159
LN.SN	2	1.9302	0.9651	2.06	0.135
N.SN	1	0.0004	0.0004	0.00	0.978
CS.LN.N	4	1.2344	0.3086	0.66	0.622
CS.LN.SN	4	3.4404	0.8601	1.84	0.131
CS.N.SN	2	0.9180	0.4590	0.98	0.380
LN.N.SN	2	1.4246	0.7123	1.52	0.225
CS.LN.N.SN	4	0.7570	0.1893	0.40	0.805
Residual	70	32.7298	0.4676		
Total	107	70.7707			

F. Cowpea seed per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.389	1.195	0.80	
Rep.*Units* stratum					
Cropping system (CS)	2	11.747	5.874	3.94	0.024
Location (LN)	2	46.559	23.280	15.60	<.001
Nitrogen (N)	1	2.225	2.225	1.49	0.226
Season (SN)	1	11.021	11.021	7.39	0.008
CS.LN	4	2.495	0.624	0.42	0.795
CS.N	2	1.872	0.936	0.63	0.537
LN.N	2	8.801	4.401	2.95	0.059
CS.SN	2	2.276	1.138	0.76	0.470
LN.SN	2	14.137	7.069	4.74	0.012
N.SN	1	0.033	0.033	0.02	0.881
CS.LN.N	4	0.231	0.058	0.04	0.997
CS.LN.SN	4	24.792	6.198	4.15	0.004
CS.N.SN	2	0.367	0.184	0.12	0.884
LN.N.SN	2	4.036	2.018	1.35	0.265
CS.LN.N.SN	4	10.406	2.601	1.74	0.150
Residual	70	104.451	1.492		
Total	107	247.839			

G. Cowpea pod mass at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	273484.	136742.	0.33	
Rep.*Units* stratum					
Cropping system (CS)	2	26993921.	13496961.	32.74	<.001
Location (LN)	2	31220042.	15610021.	37.86	<.001
Nitrogen (N)	1	15853.	15853.	0.04	0.845
Season (SN)	1	33278356.	33278356.	80.72	<.001
CS.LN	4	5678917.	1419729.	3.44	0.013
CS.N	2	454351.	227175.	0.55	0.579
LN.N	2	851303.	425651.	1.03	0.362
CS.SN	2	472761.	236381.	0.57	0.566
LN.SN	2	24785824.	12392912.	30.06	<.001
N.SN	1	67106.	67106.	0.16	0.688
CS.LN.N	4	914209.	228552.	0.55	0.696
CS.LN.SN	4	1753872.	438468.	1.06	0.381
CS.N.SN	2	807553.	403777.	0.98	0.381
LN.N.SN	2	185227.	92613.	0.22	0.799
CS.LN.N.SN	4	2714564.	678641.	1.65	0.172
Residual	70	28860375.	412291.		
Total	107	159327719.			

H. Cowpea grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	69067.	34533.	0.22	
Rep.*Units* stratum					
Cropping system (CS)	2	16913954.	8456977.	52.87	<.001
Location (LN)	2	11951214.	5975607.	37.36	<.001
Nitrogen (N)	1	21885.	21885.	0.14	0.713
Season (SN)	1	19126707.	19126707.	119.58	<.001
CS.LN	4	1732081.	433020.	2.71	0.037
CS.N	2	385583.	192792.	1.21	0.306
LN.N	2	754949.	377475.	2.36	0.102
CS.SN	2	1234462.	617231.	3.86	0.026
LN.SN	2	15477192.	7738596.	48.38	<.001
N.SN	1	1934.	1934.	0.01	0.913
CS.LN.N	4	84999.	21250.	0.13	0.970
CS.LN.SN	4	719240.	179810.	1.12	0.352
CS.N.SN	2	434420.	217210.	1.36	0.264
LN.N.SN	2	308425.	154212.	0.96	0.386
CS.LN.N.SN	4	1266337.	316584.	1.98	0.107
Residual	70	11196108.	159944.		
Total	107	81678559.			

I. Cowpea stover biomass yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	7011917.	3505958.	1.08	
Rep.*Units* stratum					
Cropping system (CS)	2	45671257.	22835629.	7.05	0.002
Location (LN)	2	131527574.	65763787.	20.30	<.001
Nitrogen (N)	1	4260248.	4260248.	1.32	0.255
Season (SN)	1	231514912.	231514912.	71.48	<.001
CS.LN	4	17979226.	4494806.	1.39	0.247
CS.N	2	3117689.	1558844.	0.48	0.620
LN.N	2	828028.	414014.	0.13	0.880
CS.SN	2	14998033.	7499016.	2.32	0.106
LN.SN	2	79496295.	39748147.	12.27	<.001
N.SN	1	919806.	919806.	0.28	0.596
CS.LN.N	4	5615967.	1403992.	0.43	0.784
CS.LN.SN	4	25132053.	6283013.	1.94	0.113
CS.N.SN	2	652438.	326219.	0.10	0.904
LN.N.SN	2	1430887.	715444.	0.22	0.802
CS.LN.N.SN	4	5839227.	1459807.	0.45	0.772
Residual	70	226716949.	3238814.		
Total	107	802712506.			

J. Cowpea plant population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	6.205E+07	3.102E+07	1.30	
Rep.*Units* stratum					
Cropping system (CS)	2	1.265E+08	6.326E+07	2.65	0.078
Location (LN)	2	2.175E+08	1.087E+08	4.55	0.014
Nitrogen (N)	1	1.078E+08	1.078E+08	4.51	0.037
Season (SN)	1	4.003E+08	4.003E+08	16.76	<.001
CS.LN	4	3.360E+07	8.401E+06	0.35	0.842
CS.N	2	3.756E+07	1.878E+07	0.79	0.460
LN.N	2	5.403E+07	2.702E+07	1.13	0.328
CS.SN	2	1.924E+07	9.618E+06	0.40	0.670
LN.SN	2	2.002E+09	1.001E+09	41.92	<.001
N.SN	1	3.551E+06	3.551E+06	0.15	0.701
CS.LN.N	4	6.754E+07	1.689E+07	0.71	0.590
CS.LN.SN	4	3.378E+07	8.446E+06	0.35	0.841
CS.N.SN	2	9.188E+07	4.594E+07	1.92	0.154
LN.N.SN	2	3.814E+07	1.907E+07	0.80	0.454
CS.LN.N.SN	4	2.171E+07	5.427E+06	0.23	0.922
Residual	70	1.672E+09	2.389E+07		
Total	107	4.990E+09			

Appendix 5.1. Analysis of variance of cowpea protein content at three locations during 2011/12 and 2012/13 planting seasons.

A. Cowpea immature leaf protein

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	21.945	10.972	5.94	
Rep.*Units* stratum					
Cropping system (CS)	2	11.898	5.949	3.22	0.046
Location (LN)	2	1007.632	503.816	272.78	<.001
Nitrogen (N)	1	7.292	7.292	3.95	0.051
Season (SN)	1	1.641	1.641	0.89	0.349
CS.LN	4	7.263	1.816	0.98	0.423
CS.N	2	3.249	1.624	0.88	0.420
LN.N	2	14.612	7.306	3.96	0.024
CS.SN	2	0.282	0.141	0.08	0.927
LN.SN	2	77.621	38.811	21.01	<.001
N.SN	1	2.696	2.696	1.46	0.231
CS.LN.N	4	25.524	6.381	3.45	0.012
CS.LN.SN	4	3.009	0.752	0.41	0.803
CS.N.SN	2	4.569	2.284	1.24	0.297
LN.N.SN	2	7.548	3.774	2.04	0.137
CS.LN.N.SN	4	5.766	1.441	0.78	0.542
Residual	70	129.290	1.847		
Total	107	1331.835			

B. Cowpea immature pod protein

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.055	1.028	0.50	
Rep.*Units* stratum					
Cropping system (CS)	2	5.478	2.739	1.35	0.267
Location (LN)	2	14.547	7.274	3.57	0.033
Nitrogen (N)	1	10.862	10.862	5.34	0.024
Season (SN)	1	106.754	106.754	52.45	<.001
CS.LN	4	9.377	2.344	1.15	0.340
CS.N	2	3.386	1.693	0.83	0.440
LN.N	2	3.660	1.830	0.90	0.412
CS.SN	2	0.893	0.446	0.22	0.804
LN.SN	2	45.118	22.559	11.08	<.001
N.SN	1	0.243	0.243	0.12	0.731
CS.LN.N	4	3.251	0.813	0.40	0.809
CS.LN.SN	4	3.649	0.912	0.45	0.773
CS.N.SN	2	1.780	0.890	0.44	0.648
LN.N.SN	2	8.911	4.455	2.19	0.120
CS.LN.N.SN	4	5.581	1.395	0.69	0.604
Residual	70	142.484	2.035		
Total	107	368.027			

C. Cowpea seed protein

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.4429	0.7215	0.92	
Rep.*Units* stratum					
Cropping system (CS)	2	0.3817	0.1909	0.24	0.784
Location (LN)	2	130.9911	65.4956	83.61	<.001
Nitrogen (N)	1	0.4537	0.4537	0.58	0.449
Season (SN)	1	0.1481	0.1481	0.19	0.665
CS.LN	4	5.5959	1.3990	1.79	0.141
CS.N	2	0.8074	0.4037	0.52	0.600
LN.N	2	3.0673	1.5337	1.96	0.149
CS.SN	2	0.9259	0.4629	0.59	0.557
LN.SN	2	119.4076	59.7038	76.21	<.001
N.SN	1	2.1888	2.1888	2.79	0.099
CS.LN.N	4	3.9541	0.9885	1.26	0.293
CS.LN.SN	4	5.3465	1.3366	1.71	0.158
CS.N.SN	2	0.1191	0.0596	0.08	0.927
LN.N.SN	2	5.5640	2.7820	3.55	0.034
CS.LN.N.SN	4	8.7140	2.1785	2.78	0.033
Residual	70	54.8357	0.7834		
Total	107	343.9440			

Appendix 6.1. Analysis of variance of maize seed quality at three locations during 2011/12 and 2012/13 planting seasons.

A. Maize seed oil content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
RP stratum	2	0.02722	0.01361	0.61	
RP.*Units* stratum					
Cropping system (CS)	2	0.00389	0.00194	0.09	0.917
Location (LN)	2	1.79167	0.89583	40.04	<.001
Nitrogen (N)	1	0.00926	0.00926	0.41	0.522
Season (SN)	1	0.01815	0.01815	0.81	0.371
CS.LN	4	0.09444	0.02361	1.06	0.385
CS.N	2	0.13019	0.06509	2.91	0.061
LN.N	2	0.07352	0.03676	1.64	0.201
CS.SN	2	0.02463	0.01231	0.55	0.579
LN.SN	2	1.23019	0.61509	27.49	<.001
N.SN	1	0.00037	0.00037	0.02	0.898
CS.LN.N	4	0.10704	0.02676	1.20	0.320
CS.LN.SN	4	0.12370	0.03093	1.38	0.249
CS.N.SN	2	0.01241	0.00620	0.28	0.759
LN.N.SN	2	0.42907	0.21454	9.59	<.001
CS.LN.N.SN	4	0.49481	0.12370	5.53	<.001
Residual	70	1.56611	0.02237		
Total	107	6.13667			

B. Maize seed protein content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
RP stratum	2	1.830	0.915	0.87	
RP.*Units* stratum					
Cropping system (CS)	2	3.391	1.696	1.61	0.207
Location (LN)	2	16.623	8.311	7.89	<.001
Nitrogen (N)	1	16.725	16.725	15.88	<.001
Season (SN)	1	20.367	20.367	19.33	<.001
CS.LN	4	7.590	1.897	1.80	0.138
CS.N	2	3.412	1.706	1.62	0.205
LN.N	2	9.703	4.851	4.61	0.013
CS.SN	2	3.477	1.738	1.65	0.199
LN.SN	2	29.761	14.880	14.13	<.001
N.SN	1	1.841	1.841	1.75	0.191
CS.LN.N	4	4.341	1.085	1.03	0.398
CS.LN.SN	4	4.260	1.065	1.01	0.408
CS.N.SN	2	0.377	0.189	0.18	0.836
LN.N.SN	2	2.442	1.221	1.16	0.320
CS.LN.N.SN	4	2.261	0.565	0.54	0.709
Residual	70	73.743	1.053		
Total	107	202.143			

C. Maize seed starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
RP stratum	2	2.667	1.334	1.27	
RP.*Units* stratum					
Cropping system (CS)	2	1.060	0.530	0.50	0.606
Location (LN)	2	40.978	20.489	19.47	<.001**
Nitrogen (N)	1	0.222	0.222	0.21	0.647
Season (SN)	1	122.667	122.667	116.56	<.001**
CS.LN	4	3.450	0.862	0.82	0.517
CS.N	2	1.408	0.704	0.67	0.515
LN.N	2	2.934	1.467	1.39	0.255
CS.SN	2	2.318	1.159	1.10	0.338
LN.SN	2	1.080	0.540	0.51	0.601
N.SN	1	4.771	4.771	4.53	0.037*
CS.LN.N	4	3.419	0.855	0.81	0.522
CS.LN.SN	4	1.018	0.254	0.24	0.914
CS.N.SN	2	3.026	1.513	1.44	0.244
LN.N.SN	2	3.942	1.971	1.87	0.161
CS.LN.N.SN	4	4.226	1.057	1.00	0.411
Residual	70	73.666	1.052		
Total	107	272.852			

D. Maize seed phosphorus content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
RP stratum	2	0.028857	0.014429	1.95	
RP.*Units* stratum					
Cropping system (CS)	2	0.043557	0.021779	2.95	0.050
Location (LN)	2	0.004141	0.002070	0.28	0.756
Nitrigen (N)	1	0.053779	0.053779	7.28	0.009
Season (SN)	1	0.712156	0.712156	96.42	<.001
CS.LN	4	0.051543	0.012886	1.74	0.150
CS.N	2	0.005680	0.002840	0.38	0.682
LN.N	2	0.044319	0.022159	3.00	0.056
CS.SN	2	0.025535	0.012768	1.73	0.185
LN.SN	2	0.390807	0.195404	26.46	<.001
N.SN	1	0.027712	0.027712	3.75	0.057
CS.LN.N	4	0.021798	0.005450	0.74	0.569
CS.LN.SN	4	0.022943	0.005736	0.78	0.544
CS.N.SN	2	0.000880	0.000440	0.06	0.942
LN.N.SN	2	0.022963	0.011481	1.55	0.218
CS.LN.N.SN	4	0.027887	0.006972	0.94	0.444
Residual	70	0.517009	0.007386		
Total	107	2.001566			

Appendix 7.1. Analysis of variance of soil chemical properties at three locations during 2011/12 and 2012/13 planting seasons.

A. Soil organic carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	1	1.83925	1.83925	30.43	
Rep.*Units* stratum					
Cropping system (CS)	4	0.87254	0.21813	3.61	0.008
Location (LN)	2	15.63095	7.81548	129.31	<.001
Nitrogen (N)	1	0.04959	0.04959	0.82	0.367
Soil depth (SD)	1	0.11397	0.11397	1.89	0.172
Season (SN)	1	1.34550	1.34550	22.26	<.001
CS.LN	8	0.61646	0.07706	1.27	0.263
CS.N	4	0.09256	0.02314	0.38	0.821
LN.N	2	0.06760	0.03380	0.56	0.573
CS.SD	4	0.15827	0.03957	0.65	0.625
LN.SD	2	0.23075	0.11538	1.91	0.153
N.SD	1	0.04565	0.04565	0.76	0.387
CS.SN	4	0.03968	0.00992	0.16	0.956
LN.SN	2	1.55836	0.77918	12.89	<.001
N.SN	1	0.00950	0.00950	0.16	0.692
SD.SN	1	0.03577	0.03577	0.59	0.443
CS.LN.N	8	0.34684	0.04336	0.72	0.676
CS.LN.SD	8	0.27355	0.03419	0.57	0.804
CS.N.SD	4	0.08560	0.02140	0.35	0.841
LN.N.SD	2	0.10825	0.05413	0.90	0.411
CS.LN.SN	8	0.44938	0.05617	0.93	0.495
CS.N.SN	4	0.06783	0.01696	0.28	0.890
LN.N.SN	2	0.07210	0.03605	0.60	0.552
CS.SD.SN	4	0.03982	0.00995	0.16	0.956
LN.SD.SN	2	0.07076	0.03538	0.59	0.558
N.SD.SN	1	0.00513	0.00513	0.08	0.771
CS.LN.N.SD	8	0.08597	0.01075	0.18	0.994
CS.LN.N.SN	8	0.57567	0.07196	1.19	0.310
CS.LN.SD.SN	8	0.20190	0.02524	0.42	0.909
CS.N.SD.SN	4	0.04881	0.01220	0.20	0.937
LN.N.SD.SN	2	0.13348	0.06674	1.10	0.335
CS.LN.N.SD.SN	8	0.14350	0.01794	0.30	0.966
Residual	119	7.19250	0.06044		
Total	239	32.60748			

B. Post-harvest soil P (Bray 1-P)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	1	138.02	138.02	3.03	
Rep.*Units* stratum					
Cropping system (CS)	4	791.18	197.80	4.34	0.003
Location (LN)	2	7607.76	3803.88	83.46	<.001
Nitrogen (N)	1	96.27	96.27	2.11	0.149
Soil depth (SD)	1	8283.75	8283.75	181.74	<.001
Season (SN)	1	370.02	370.02	8.12	0.005
CS.LN	8	367.87	45.98	1.01	0.433
CS.N	4	286.98	71.75	1.57	0.186
LN.N	2	6.16	3.08	0.07	0.935
CS.SD	4	155.08	38.77	0.85	0.496
LN.SD	2	1843.27	921.64	20.22	<.001
N.SD	1	70.42	70.42	1.54	0.216
CS.SN	4	111.65	27.91	0.61	0.655
LN.SN	2	35.36	17.68	0.39	0.679
N.SN	1	36.82	36.82	0.81	0.371
SD.SN	1	21.60	21.60	0.47	0.493
CS.LN.N	8	114.72	14.34	0.31	0.959
CS.LN.SD	8	215.02	26.88	0.59	0.785
CS.N.SD	4	75.08	18.77	0.41	0.800
LN.N.SD	2	154.41	77.20	1.69	0.188
CS.LN.SN	8	954.10	119.26	2.62	0.011
CS.N.SN	4	330.18	82.55	1.81	0.131
LN.N.SN	2	9.76	4.88	0.11	0.899
CS.SD.SN	4	72.98	18.25	0.40	0.808
LN.SD.SN	2	17.57	8.79	0.19	0.825
N.SD.SN	1	4.27	4.27	0.09	0.760
CS.LN.N.SD	8	191.97	24.00	0.53	0.835
CS.LN.N.SN	8	273.62	34.20	0.75	0.647
CS.LN.SD.SN	8	327.22	40.90	0.90	0.521
CS.N.SD.SN	4	129.98	32.50	0.71	0.585
LN.N.SD.SN	2	100.31	50.15	1.10	0.336
CS.LN.N.SD.SN	8	108.57	13.57	0.30	0.965
Residual	119	5423.98	45.58		
Total	239	28725.93			

C. Post-harvest soil nitrate (N-NO_3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	1	1.095	1.095	0.88	
Rep.*Units* stratum					
Cropping system (CS)	4	136.655	34.164	27.42	<.001
Location (LN)	2	24.455	12.227	9.81	<.001
Nitrogen (N)	1	9.068	9.068	7.28	0.008
Soil depth (SD)	1	153.104	153.104	122.89	<.001
SN	1	3.321	3.321	2.67	0.105
CS.LN	8	43.471	5.434	4.36	<.001
CS.N	4	22.233	5.558	4.46	0.002
LN.N	2	5.085	2.542	2.04	0.134
CS.SD	4	20.252	5.063	4.06	0.004
LN.SD	2	11.964	5.982	4.80	0.010
N.SD	1	1.373	1.373	1.10	0.296
CS.SN	4	0.086	0.021	0.02	0.999
LN.SN	2	199.792	99.896	80.18	<.001
N.SN	1	0.025	0.025	0.02	0.888
SD.SN	1	3.434	3.434	2.76	0.099
CS.LN.N	8	20.534	2.567	2.06	0.045
CS.LN.SD	8	17.698	2.212	1.78	0.088
CS.N.SD	4	2.795	0.699	0.56	0.692
LN.N.SD	2	0.714	0.357	0.29	0.751
CS.LN.SN	8	16.779	2.097	1.68	0.109
CS.N.SN	4	16.684	4.171	3.35	0.012
LN.N.SN	2	14.155	7.078	5.68	0.004
CS.SD.SN	4	2.836	0.709	0.57	0.685
LN.SD.SN	2	25.466	12.733	10.22	<.001
N.SD.SN	1	0.007	0.007	0.01	0.940
CS.LN.N.SD	8	8.139	1.017	0.82	0.589
CS.LN.N.SN	8	13.098	1.637	1.31	0.243
CS.LN.SD.SN	8	8.136	1.017	0.82	0.590
CS.N.SD.SN	4	1.456	0.364	0.29	0.883
LN.N.SD.SN	2	1.010	0.505	0.41	0.668
CS.LN.N.SD.SN	8	6.670	0.834	0.67	0.718
Residual	119	148.256	1.246		
Total	239	939.844			

D. Post-harvest soil ammonium (N-NH4)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	1	0.00088	0.00088	0.01	
Rep.*Units* stratum					
Cropping system (CS)	4	0.15379	0.03845	0.48	0.751
Location (LN)	2	12.87237	6.43619	80.13	<.001
Nitrogen (N)	1	0.00033	0.00033	0.00	0.949
Soil depth (SD)	1	1.24416	1.24416	15.49	<.001
Season (SN)	1	1.80961	1.80961	22.53	<.001
CS.LN	8	0.52019	0.06502	0.81	0.596
CS.N	4	0.58438	0.14609	1.82	0.130
LN.N	2	0.29674	0.14837	1.85	0.162
CS.SD	4	0.52101	0.13025	1.62	0.173
LN.SD	2	0.93232	0.46616	5.80	0.004
N.SD	1	0.02091	0.02091	0.26	0.611
CS.SN	4	0.13959	0.03490	0.43	0.784
LN.SN	2	2.43548	1.21774	15.16	<.001
N.SN	1	0.02646	0.02646	0.33	0.567
SD.SN	1	0.24576	0.24576	3.06	0.083
CS.LN.N	8	0.50180	0.06272	0.78	0.620
CS.LN.SD	8	0.34427	0.04303	0.54	0.828
CS.N.SD	4	0.10406	0.02601	0.32	0.862
LN.N.SD	2	0.28233	0.14117	1.76	0.177
CS.LN.SN	8	1.04641	0.13080	1.63	0.124
CS.N.SN	4	0.40766	0.10192	1.27	0.286
LN.N.SN	2	0.24653	0.12326	1.53	0.220
CS.SD.SN	4	0.55116	0.13779	1.72	0.151
LN.SD.SN	2	0.02919	0.01460	0.18	0.834
N.SD.SN	1	0.00024	0.00024	0.00	0.957
CS.LN.N.SD	8	0.58497	0.07312	0.91	0.511
CS.LN.N.SN	8	0.77609	0.09701	1.21	0.300
CS.LN.SD.SN	8	0.16015	0.02002	0.25	0.980
CS.N.SD.SN	4	0.18772	0.04693	0.58	0.675
LN.N.SD.SN	2	0.04862	0.02431	0.30	0.739
CS.LN.N.SD.SN	8	0.58068	0.07258	0.90	0.516
Residual	119	9.55882	0.08033		
Total	239	37.21466			

E. Post-harvest soil exchangeable K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	1	799.3	799.3	1.34	
Rep.*Units* stratum					
Cropping system (CS)	4	4064.3	1016.1	1.70	0.153
Location (LN)	2	706219.3	353109.6	592.42	<.001
Nitrogen (N)	1	312.8	312.8	0.52	0.470
Soil depth (SD)	1	76826.8	76826.8	128.89	<.001
Season (SN)	1	858.8	858.8	1.44	0.232
CS.LN	8	9042.6	1130.3	1.90	0.067
CS.N	4	3021.6	755.4	1.27	0.287
LN.N	2	3526.3	1763.2	2.96	0.056
CS.SD	4	3462.8	865.7	1.45	0.221
LN.SD	2	50164.9	25082.5	42.08	<.001
N.SD	1	126.1	126.1	0.21	0.646
CS.SN	4	4327.5	1081.9	1.82	0.130
LN.SN	2	3803.9	1901.9	3.19	0.045
N.SN	1	340.8	340.8	0.57	0.451
SD.SN	1	1353.8	1353.8	2.27	0.134
CS.LN.N	8	4437.9	554.7	0.93	0.494
CS.LN.SD	8	4746.3	593.3	1.00	0.443
CS.N.SD	4	128.4	32.1	0.05	0.995
LN.N.SD	2	859.1	429.5	0.72	0.489
CS.LN.SN	8	1398.5	174.8	0.29	0.967
CS.N.SN	4	2162.4	540.6	0.91	0.462
LN.N.SN	2	700.4	350.2	0.59	0.557
CS.SD.SN	4	3470.7	867.7	1.46	0.220
LN.SD.SN	2	526.8	263.4	0.44	0.644
N.SD.SN	1	889.3	889.3	1.49	0.224
CS.LN.N.SD	8	2852.5	356.6	0.60	0.778
CS.LN.N.SN	8	10160.3	1270.0	2.13	0.038
CS.LN.SD.SN	8	4824.8	603.1	1.01	0.431
CS.N.SD.SN	4	1186.0	296.5	0.50	0.738
LN.N.SD.SN	2	1049.9	525.0	0.88	0.417
CS.LN.N.SD.SN	8	1681.1	210.1	0.35	0.943
Residual	119	70929.7	596.0		
Total	239	980255.9			