Growth and yield responses of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) in an intercropping system

By

Thobatsi Thobatsi

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Department of Plant Production and Soil Science
University of Pretoria

Supervisor: Prof C.F Reinhardt
Co-Supervisor: Dr J.M Steyn
Mentor: Mr. M.A. Prinsloo

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DECLARATION

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

Signed:_________________ Date________________

Thobatsi Jacob Thobatsi

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
BNF	Biological Nitrogen Fixation
CV	Coefficient of variation
cm	Centimeter
DMY	Dry matter yield
g	Gram
GCI	Grain Crops Institute
ha^{-1}	Per hectare
IIC	Institute for Industrial Crops
kg	Kilogram
LAI	Leaf Area Index
mg	Milligram
N	Nitrogen
NH_4^+	Ammonium
NO_3^-	Nitrate
Ns	Non significant
P	Phosphorus
PAR	Photosynthetic Active Radiation
RUE	Radiation Use Efficiency
WUE	Water Use Efficiency
%	Percentage

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ABSTRACT

Growth and yield responses of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) in an intercropping system

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Maize is the third most important cereal crop in the world and many subsistence farmers are practicing intercropping of it with legumes due to land scarcity and in order to enhance production. Intercropping system is being practiced in may areas of South Africa mainly in the Limpopo province. The objective of the study was to evaluate the crop responses to intercropping maize with different growth length cowpea cultivars. The effects of intercropping on weed growth, maize and cowpea growth and yield components were investigated. The experiment was conducted during the 2005/06 and 2006/07 seasons at Bethlehem and Potchefstroom. Treatments were: maize sole, maize+PAN311 (short duration cowpea cultivar), maize+Glenda (medium duration cowpea cultivar), maize+Agrinawa (long duration cowpea cultivar) and sole plots of all cowpea varieties. Each plot was divided into two weed levels where all the plots were kept weed free for one month after planting, after which one half was left weedy and the other half weed free. Weed sampling was done within each weed treatment. Intercropping reduced maize LAI and plant height while time to physiological maturity was also reduced by weed infestation, especially under drier and warmer environments. Glenda and Agrinawa intercrops produced more nodules per plant under cooler and wetter conditions. Agrinawa produced the highest leaf and total DMY under sole crop conditions and this was significantly reduced by weed infestation. Different growth duration cultivars did not differ in their N_2-binding abilities. Maize intercropping, especially with Glenda and Agrinawa, significantly reduced weed biomass. Maize sole crop under zero weeds had high grain yield compared to intercropping. PAN311 and Glenda sole crops under zero weeds produced higher yields under dry and warmer conditions, and cooler and wetter conditions, respectively, compared to intercropping. High cowpea grain yields were strongly correlated to more seeds per pod and larger pod lengths and number of pods per plant especially for Glenda. No intercropping advantage compared to sole cropping was observed (total LER < 1). This implies that maize and cowpeas must rather be planted as sole crops for better yields under wetter and cooler, and warmer and drier conditions.

Keywords: cowpea, growth parameters, intercropping, LER, maize, weed, yield parameters.

GENERAL INTRODUCTION

Intercropping is the growing of two or more crops on the same piece of land within the same year to promote their interaction and it also maximizes chances of productivity by avoiding dependence on only one crop (Sullivan, 2003). Various intercropping patterns of legumes and non-legumes have been a central feature of many agricultural systems in the tropics (Willey, 1979; CIAT, 1986). Vandermeer (1989) has proposed that intercropping be divided into three general categories; full, relay and sequential intercropping and that preference depends on the extent of physical association between the crops. There are several socio economic factors (Ofori & Stern, 1987), and biological as well as ecological (Van Rheenen, Hasselback & Muigai, 1981; Aggarwal *et al*., 1992; Chemeda, 1996) advantages to intercropping relative to sole cropping for smallholder farmers. Intercropping is a principal means of intensifying crop production and to improve returns from limited land holdings (Storck *et al*., 1991), and in the tropics maize and cowpea are often intercropped (Van Kessel & Roskoski, 1988). Suitable land area for agricultural production remains fixed or is diminishing, yet farmers are faced with the task of increasing production demands. Raising productivity, through adequate use of available natural resources e.g. light and nutrients, is possible through intercropping provided demands for component crops are well understood (Midmore, 1993).

Maize (*Zea mays* L.) is one of the oldest food sources and is a fully domesticated plant. Humans and maize have lived and evolved together since ancient times. Modern maize does not grow in the wild, cannot survive in nature and is completely dependent on human husbandry (Galinant, 1988; Doswell, Paliwal & Cantrell, 1996). It is a productive food plant and has the highest potential for carbohydrate accumulation per unit area per day (Aldrich, Scott & Leng, 1975). In an African context maize is, in terms of production, the most important grain cereal before wheat, with rice occupying third place. It is the top ranking cereal in grain yield per hectare and is second to wheat in total production. Maize is of great economic significance world wide, both for human and animal consumption and is the source of a large number of industrial products. Maize has multifarious uses and the diversity of environments under which it is grown, is therefore, unmatched by any other crop (Doswell *et al*., 1996).

Maize is South Africa's most important field crop since it is the staple food for a major part of the population and with the major producing areas being North West (840 000 ha), Free State (750 000 ha) and Mpumalanga (270 000 ha) provinces (CEC, 2007). Maize can be produced in areas where rainfall exceeds 350 mm per year with production dependent on rainfall distribution throughout the year. Dryland area production is normally conducted on 34 % of the Free State, 32% of North West, 24% of Mpumalanga and 3% of KwaZulu Natal. Total area planted ranges between 3.8 and 4.8 million ha, which represents approximately 25% of the country's arable land. In the past ten years, an average of 8.2 million tons of maize was produced of which subsistence farmers produced an average of 500 000 tons mainly for annual house hold consumption (NDoA, 2000). During the 2005/06 growing season, 1 600 200 ha of arable land was planted with maize from which, 6 618 000 tons of grain was produced. Free State was the leading province in terms of production with 2 080 00 tons, followed by the North West with 1 690 000 tons and Mpumalanga with 1 615 000 tons (CEC, 2007).

Cowpea (*Vigna unguiculata* (L.) Walp) is also an important staple food for millions of relatively poor people in less developed countries (Coetzee, 1995). Growth forms vary and may be erect, trailing, climbing or bushy and usually indeterminate under favorable conditions. Cowpea is a heat-loving, drought-tolerant crop with high protein content (22-24%) and can thrive in lower soil fertility conditions than many other crops (Coetzee, 1995). These properties, and the presence of nodular bacteria specific to cowpea (*Bradyrhizobium* spp.), make it suitable for cultivation in the hot, marginal cropping areas of Southern Africa as well as in the cooler, higher rainfall areas. In Southern Africa, cowpea is at present planted primarily for fodder, although it is also used for grain production, green manure, and weed control as a cover or anti-erosion crop. In South Africa, cowpea production is relatively low in magnitude compared to other crops due to lack of economic support for production. In contrast to most other crops, no coordinating body exists for cowpea production in South Africa (Quass, 1995). A strong need exist for research on cowpea production, transportation and marketing opportunities for consumer preferences and identification of areas with competitive advantages in Southern Africa (Lowenberg-DeBoer, Fulton & Coulibaly, 2007).

Cowpea variety selection is the key to the modification of cropping systems and is exceptionally suitable for intercropping (Singh *et al*., 2002). According to Nelson &

Robichaux (1997) this is important, as different plant traits are required for cultivars intended for use under intercropping compared to sole cropping. Terao *et al*. (1997) concluded that spreading cowpea types are more adapted to intercropping because of improved root systems and high translocation efficiency and are also believed to give better weed control and conserve moisture. Nelson & Robichaux (1997) reported that cultivars with bush type growth patterns have higher yield under sole cropping whereas spreading types have higher yield under intercropping. The climbing cowpea types with long growth duration have higher nutrient and water uptake than the short bush type cowpea cultivars (Polthanee *et al*., 2001) Subsistence farmers require varieties, which produce acceptable grain and fodder yields under a wide range of environments.

Intercropping is most likely to be practiced on small farms in areas where land is scarce, forcing the simultaneous production of different crops on the same area of land. Lower rainfall and/or an uneven distribution of rain may encourage intercropping as farmers try to maximize their use of water, although, in the extreme, this can result in competition for scarce resources. Intercropping techniques are also more likely to be used by farmers relying on handheld implements for cultivation (Ruthernburg, 1980). Growing interest of mixed cropping in developed countries (Ofori & Stern, 1987) stems from an increased awareness of environmental degradation arising from high chemical inputs (Nielson & Mackenzie, 1977) and gives rise to a search for ways to reduce modern agriculture's over dependence on fertilizers, manufactured mainly with use of fossil energy and the use of herbicides for weed control. The maintenance of a complete crop canopy over the soil inhibits weed seed germination and reduces the need for weeding. Early canopy development, inhibits early weed development and reduces weed-crop competition, particularly for soil nutrients and water. Benefits from intercropping for weed control are particularly evident under low input conditions and increases in component crop yields have been attributed to improved weed control (Leihner, 1979). Most farmers in developing countries who have adopted this low input system have done so principally for climatic and socio-economic reasons based on varieties (Okigbo & Greenland, 1976).

Crop mixtures may consist of legume/legume (Rao & Mittra, 1989) or legume/non-legume systems (Mandal *et al*., 1990). However, mixed cropping of cereal-legume is wide spread (Ofori & Stern, 1987) because legumes used in crop production have traditionally enabled farmers to cope with soil erosion and with declining levels of soil organic matter and available N (Scott *et al*., 1987). In intercropping, where different plant species are grown in close proximity, the growth of one plant is affected by the other. According to Rice (1974), allelopathy is an essential phenomenon that refers to any direct or indirect harmful or beneficial effect of one plant (including micro-organisms) on another plant through production of chemical compounds excreted into its growth environment. Planting mixtures in the presence of weeds are more likely to result in more advantages of allelopathic effects on plants (Creamer & Bennet, 1997).

The main disadvantages of intercropping systems may comprise of planting, managing fertilization, weed control, pest control and harvesting for both crops as it is normally done manually by small-scale farmers (Sullivan, 2003). The main advantages of intercropping are the reduction in risk for total crop failure, and in product diversification- food crops are often mixed with cash crops to help ensure both subsistence and disposable income (Vandermeer, 1989; Singh & Jodha, 1990). In intercropping systems, the microclimate surrounding the lower crop is more conductive to plant growth than in a sole crop (Matthews *et al*., 1991), and the intercrop is more efficient at using resources such as light, water and nutrients (Azam-Ali *et al*., 1990). Moreover, main crop yields can be reduced by intercropping techniques, both as a result of loss of land to the legume, and also to competition for growth resources (Vandermeer, 1989; Snapp, Mafongoya & Waddington, 1998). In the long term, cereal/legume intercrops are still likely to require fertilizers for the provision of Phosphorus (P), Potassium (K) and micronutrients in order to maintain satisfactory yields (Coultas *et al*., 1996; Kumwenda *et al*., 1997). Biological Nitrogen Fixation (BNF), which enables legumes to utilize atmospheric N, is important in legume based cropping systems when fertilizer N is limited. BNF contributes N for legume growth and grain production under different environmental and soil conditions. In addition, soil may be replenished with N through decomposition of legume residues when BNF contributes more N than the seed requires. Evidence also suggests that associated cereals may benefit through N transfer from legumes (Fujita *et al*., 1990).

Yield advantages from intercropping as compared to sole cropping are often attributed to mutual complementary effects of component crops, such as better total use of available resources. Generally, monoculture legumes have higher yields compared to an intercropping system. However, in most cases, land productivity, measured by Land

Equivalent Ratio (LER), clearly shows the advantage of mixed cropping of cereals and legumes (Yunusa, 1989 & Mandal *et al.*, 1990). Depending on component crops, yield advantage may vary considerably due to several factors, including differences in plant architecture, rooting patterns, competitive advantages and potential nitrogen fixing capacity of the legume. These, in turn, determine the optimum density, time of sowing and amount of fertilizer N. The need for simultaneous production of different food crops and/or cash crops can also encourage intercropping. Relatively better-off farmers with large farms are less reliant on intercropping, being able to fallow and/or control production with other inputs such as water and inorganic fertilizers.

This study encompasses the comparison of maize/cowpea intercropping practices with different growth duration cowpea cultivars against sole maize and cowpea systems. The objectives are:

i. To determine the crop responses to intercropping maize with different seasonal growth length cowpea cultivars;
ii. To evaluate nodulation and N_2-fixation of cowpea varieties with different seasonal growth duration in the system;
iii. To evaluate the possible weed suppression effects of different cowpea varieties of different growth duration;
iv. To evaluate the influence of weed occurrence on crop responses of sole and intercropped maize and cowpea.

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CHAPTER 1: LITERATURE REVIEW

Joint cultivation of two or more crops at the same time on the same piece of land is referred to as intercropping (Sullivan, 2003), and is an age-old, widespread practice in the warmer climates of the world (Agboola & Fayemi, 1972; Searle *et al*., 1981), especially the tropics (Willey, 1979). This practice allows maximum benefit to be made of natural resources available for production. The interest of growing two or more crops at the same time on the same piece of land is increasing because of the potential to increase an area's productivity (Fortin & Pierce, 1996). Total grain and plant N yield can often be increased by intercropping legumes with non-legumes (Barker & Blamey, 1985; Singh, Singh & Nair, 1986). While intercropping has been practiced for centuries, the interest of agricultural scientists in such crop production systems has only recently increased (Willey, 1979). Conflicting reports exist about whether a non-legume benefits from N supplied by an intercropped legume. In some instances the N contribution of the intercropped legume to maize has been estimated to be up to 40 kg ha^{-1} (Willey, 1979) while other investigators did not find any evidence for such N benefits (Wahua & Muller, 1978; Searle *et al*., 1981).

1.1. Intercropping as a practice

The cultivation of two or more crops simultaneously on the same piece of land can be subdivided into four different categories. Grossman and Quarles (1993) divided intercropping into four basic spatial arrangements, which seem most practical:

i. Row intercropping: planting of two or more crops simultaneously with both crops planted in distinctive rows.
ii. Strip intercropping: planting of two or more crops together in strips wide enough to permit separate crop production practices using machines, but close enough for the crops to interact.
iii. Mixed intercropping: planting of two or more crops together without any distinct row arrangement.
iv. Relay intercropping: planting of a second crop into an already standing crop at a time when the standing crop is at its reproductive stage or has completed its development, but before harvesting.

The primary objective of all farmers is to sustain production (Barker & Norman, 1975) at reasonable levels and at low risks in order to sustain their needs (Beets, 1990). Most of farmer's needs have increased due to the increased population and subsequent reduction in arable land per unit capita. Therefore, the important approach to increase agricultural production is to improve yield of individual crops per unit area at disposal. Farmers with limited resources have limited capacity to tolerate production failure and, therefore, are compelled to practice intercropping where a legume is combined with a cereal as a nutritious food and fodder source (Henriet *et al*., 1997). Resource poor farmers mostly practice intercropping because of limited land but also for the beneficial interaction regarding chemical application. Sole crops require more chemicals to control insect pests and diseases and these chemicals (pesticides, herbicides and insecticides) may not be available even if financial resources are available (Singh & Adjeigbe, 2002).

1.2. Intercropping advantages and disadvantages

Among the various combinations of cereals and legumes used by small-scale farmers, maize and cowpea is one of the most widely used (Eaglesham *et al*., 1981; Ofori & Stern, 1986 and Mpangane *et al*, 2004). The principal reasons for farmers to intercrop are flexibility, profit maximization, risk minimization against crop failure, soil conservation and maintenance, weed control and balanced nutrition (Shetty *et al*., 1995). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field. Time labour management, and equipment are also better utilized (McCoy *et al*., 2001). According to Viljoen & Allemann (1996), some of intercropping advantages include: higher yield than sole crop yields, probably due to less intra-specific competition, greater yield stability, more efficient use of environmental resources, better weed control, provision of insurance against crop failure, improved quality by variety, also maize as a sole crop requires a larger area to produce the same yield as maize in an intercropping system. Mixed cropping of cereals and legumes is widespread (Ofori & Stern, 1987) because legumes used in crop production have traditionally enabled farmers to cope with soil erosion and with declining levels of soil organic matter and available N (Scott *et al*., 1987). Intercrops are believed to perform better than sole crops because of increased yield, preservation of moisture and shelter against pest attacks and even regarding the distribution of labour requirements and the provision of more balanced food supplies for humans (Vandermeer, 1992). During growth, crops even differ in the way they use their environmental resources. Research has not only focused on the yield advantage of intercropping but also through searching of detailed knowledge on how different species are able to "coexist" productively (Vandermeer, 1989). The basic ideas are based on how different species interact during intercropping. Competition for resources arises from varying time of planting, root growth patterns and different resource demands (Ghaffarzadeh, Prechac & Curse, 1997).

Cereal-legume intercropping is more common in many developing countries of Asia, Africa and South America with its advantage over sole cropping being influenced by factors such as habitat, soil fertility and moisture level as well crop varieties and species (Vandermeer, 1992). Despite the importance of such a system, very limited sources are available in the literature concerning the impact of these systems on the environment and physiology of component species. Filho (2000) concluded that, intercropped maize is more competitive than cowpea in terms of use of available resources, mainly soil water. The major disadvantage is that intercropping is not well adapted to very dry, poorly drained and heavy clay soils and also implies difficulty in harvesting, using machinery (Prochaska, 2001). Difficulty in mechanization such as sowing, weeding, fertilizing and harvesting are made for uniform fields, therefore, intercropping on large scale using machinery is generally believed to be impossible although there are intercropping examples using modern machines that exists (Ghaffarzadeh, 1999 & Baumann, 2001).

1.2.1. Water Use Efficiency (WUE)

Availability of water is one of the most important factors determining productivity in legume/cereal cropping systems. Farmers in the semi-tropical regions under rainfed conditions usually practise mixed cropping. According to Ofori & Stern (1987), cereals and legumes use water equally and competition for water may not be important in determining intercrop efficiency, except under unfavourable conditions. Water use by intercrops has mostly been studied in terms of water use efficiency (WUE). An intercrop of two crop species such as legumes and cereals may use water more efficiently than a monoculture of either species through exploring a larger total soil volume for water, especially if the component crops have different rooting patterns (Willey, 1979). Hulugalle & Lal (1986) reported that WUE in a maize/cowpea intercrop was higher than in the sole crops when soil water was not limiting. However, under water limiting conditions, WUE in the intercrop compared to sole maize can be higher resulting in retarded growth and reduced yield.

1.2.2. Nutrient Use Efficiency (NUE)

A possible advantage of intercropping legumes with non-legumes may be more efficient use of soil nutrients. If both species have different rooting and uptake patterns, more efficient use of available nutrients may occur and higher total N-uptake in intercropping systems compared to monoculture systems have been reported (Dalal, 1974; Masson, Leihner & Vorst, 1986). It is unclear, however, if better nutrient uptake is the cause or the effect of higher yield potential (Willey, 1979). At high levels of nitrogen, especially under intercropping, grain and legume yield was found to be reduced by the maize intercrop (Ezumah *et al*., 1987; Ofori & Stern, 1987). Other researchers have reported a decrease in maize yield under intercropping (Shumba *et al*., 1990; Siame *et al*., 1998). The inconsistency of cereal and legume intercropping performance requires critical investigation in areas where farmers are to benefit from intercropping in that specific locality (Mpangane *et al*., 2004). Recent efforts to improve soil fertility have been through the introduction of legumes as an intercrop and in rotation to minimize external inputs.

1.2.3. Radiation Use Efficiency (RUE)

Solar radiation provides energy for photosynthesis, which ultimately sets the potential for crop productivity and also determines water use by the process involved in evaporation and transpiration (Goudriaan, 1982; Keating & Carberry, 1993). Photosynthetically active radiation (PAR), which is utilized by green leaves, conservatively makes up about 50% of global short wave radiation (Szeicz, 1974). Compared to high variability that occurs in the supply of water and nutrients to the plant, solar radiation is more reliable and used sufficiently by intercrops as they form a complete cover to allow full interception. Solar radiation cannot be stored for later use, it must be intercepted and utilized instantaneously to energize the photosynthesis process. Therefore, neighboring plants compete for solar radiation by direct interception (Keating & Carberry, 1993). Studies on crop mixtures e.g. intercropping and crop/weed interactions, have concentrated on the competition for resources between species and the emphasis in the case of competition for light has been placed on the ability of one species to compete with and shade another (Caldwell, 1987). Differences between species, plant density, developmental pattern, plant height, canopy architecture, foliage overlap, photosynthetic rate and in the assimilate reserves, result in great structural complexity in mixed-species canopies.

Leaf area index (LAI), is the amount of green leaf area per unit of ground area, which is a parameter commonly used to describe the probability of light interception in relation to crop canopies (Keating & Carberry, 1993). Great diversity in intercrop canopies is possible, resulting from the various combinations in space and time of planting date and spatial distribution, leaf size, shape and orientation and plant height. The canopy characteristics of component crops are not constant, but may change due to the presence of other crop species (Caldwell, 1987). Crop yield is closely related to assimilate production during the yield development period of crop growth, although it is difficult to relate yield directly to solar radiation because of factors that influence the relative contributions of assimilates produced at pre-anthesis and post-anthesis. According to Evans & Wardlaw (1976), shading and reduced assimilate production will have the least effect on yield if competition occurs during the vegetative growth phase. Reddy & Willey (1981) stated that, where the components of an intercrop are in direct competition for light, increased total biomass production by the crop could result in improved yields.

The capturing of radiant energy drives crop evapotranspiration, and the pattern of its interception determines the ratio of water use through crop transpiration to that lost in soil evaporation. Probably the single most disadvantage is that cowpea plants are shaded by the cereal throughout the growing season, which results in severe reduction in shoot and root growth and ultimately in low grain and fodder yields. Although cowpeas occupy 50% of the land area under intercropping, its grain and fodder yields are 10- 20% less than those in sole cropping (Singh *et al*., 1997; Terao *et al*., 1997).

1.2.4. Intercropping and weed effects

It is commonly known that intercropping reduces weed infestation and is one of the integrated weed management strategies with less effect on the environment than the use of chemical herbicides. The success of intercropping on weed control is much more diverse when different legumes are inter-planted and both the cereal and the legume are considered as main crops. The legume crop under intercropping suppresses weeds through competition for resources (Gliessman, 1983). Weed infestation causes severe yield reductions in field crops, and losses of 40-60% have been reported under sole maize cropping (Ayeni *et al*., 1984) although growing crops in a mixture usually reduces weed occurrence (Zuofa, Tariah & Isirimah, 1992). According to Olasantan, Lucas & Ezumah (1994), the practice of growing early maturing crops between widely spaced rows of long duration crops and the use of nitrogen fertilizer to enhance early ground cover, improves the suppression of weeds. In maize/cowpea intercropping, shading suppresses weed growth that suggests the superiority of cereal and legume crops over weed growth.

Olasantan *et al*. (1994) found that intercropping cassava (*Manihot esculenta*) with N-fertilizer application gave the highest LAI and the most effective light interception and hence the best weed control, highest N uptake by the plant, higher grain yields and LER. Intercropping with no N application made only a slight improvement in leaf area index, light interception and weed control over the corresponding sole cassava. Weed dry mass was significantly higher under sole-cropped cassava without N application at 4 and 8 weeks after planting and under sole maize with no fertilizer only at 8 weeks after planting, compared to other treatments. Low N fertility, limited moisture content and weed competition have been reported to also affect the LER value. Ayeni *et al*. (1984) reported that weed interference resulted in 1.43 LER while weed free plots resulted in a 1.20 LER value while Weil & McFadden (1991) also found that high fertility levels and weed stress conditions favoured intercropping advantage.

Sans & Altieri, (unpublished) investigated the effects of cover crops and the type of fertilizer (organic vs inorganic) on the structure of weed community (biomass, number of species, diversity and evenness). They found that intercropping with cover crops significantly reduced the structure of weed community but no fertilization effect was observed. In an investigation of intercropping leek (*Allium porrum*) and celery (*Apium graveolens* L.), Baumann, Bastiaans & Kropff (2003) found it to be an alternative to reduce weed growth and reproductive potential, mainly to maintain productivity. Similar results were obtained using intercropping as an integrated weed management tool, particularly for farming systems with low external inputs (Caporali *et al*., 1998; Itulya & Aguyoh, 1998; Rana & Pal, 1999; Liebman & Davis, 2000; Schoofs & Entz, 2000). The suppression of weed occurrence was also confirmed by Steiner (1984) where maize was intercropped with groundnuts (*Arachis hypogeae* L), mungbean (*Vigna radiata* L.) and sweet potato (*Impomoea batatas* L) and in all cases lead to the reduction of weed growth, yield losses and required time for weeding. It was also observed that instead of several required weedings for sole maize, only one weeding was required to accomplish the same yield. Maize intercropping with soybean was also found to reduce weeds by 39% as compared to sole maize. In a study of Ayeni *et al*. (1984), weed growth was not suppressed by intercropping maize and cowpea. It was concluded that weed growth must be controlled initially in order for a canopy to develop sufficiently enough for weed suppression in intercropped maize/cowpea systems.

1.2.5. Allelopathic effects

According to Rice (1974), allelopathy can be defined as the direct or indirect release of chemical substances into the environment by one plant to harmfully affect another plant. Ferguson & Rathinasabapathi (2003) defined allelopathy as the beneficial or harmful effect that is caused by one plant on another thus releasing chemicals from plant parts by leaching, root exudates, volatilisation, residue decomposition and other processes in both natural and agricultural systems. Allelopathy can affect many parts of the plant ecology such as plant occurrence, growth, plant succession, the structure of the plant communities, dominance, diversity and productivity. The magnitude of the effect of allelopathy depends on the extent of any other stresses, such as environmental conditions or biological factors (insect or disease pressure) that occur during the growing season. Allelopathy also plays an important role in suppressing the growth of weed species (Reigosa *et al*., 2000; Patil, Hunshal & Itual, 2002; Chung *et al*., 2003; Florentine & Fox, 2003). Planting mixtures of cover crops with cereals can take an advantage of allelopathic potential where cover crops suppress the weeds. The suppression of weeds through allelopathy has been shown to be species sensitive, therefore, a broader spectrum of weed control may be possible by growing a mixture of different crop species, each contributing allelopathic activity towards specific weed species (Creamer & Bennet, 1997). Commonly known effects of allelopathy include reduction in seed germination and seedling growth and there is no common mode of action or physiological target site for all allelochemicals (Ferguson & Rathinasabathi, 2003). However, there are some known sites of action for some allelochemicals including cell division, pollen germination, mutant uptake, photosynthesis, and specific enzyme functions.

Allelopathic inhibition is complex and can involve the interaction of different classes of chemicals like phenolic compounds, flavinoids, terponoids, alkaloids, carbohydrates, and amino acids with mixtures of different compounds sometimes having a greater allelopathic effect than individual compounds alone. Most of the chemicals are found to be inhibitory and are caused by phytotoxic substances that are actively released from the living plants into the environment through root exudation, leaching, volatilization, and passive liberation through decomposition of plant residues. These phytotoxic substances, termed allelochemicals, are usually considered to be secondary metabolites and do not appear to play a role in primary metabolism essential for plant survival (Swain, 1977). Putman (1988) identified a number of classes of allelochemicals causing inhibition of germination and growth. Factors such as physiological and environmental stress, pests and diseases, solar radiation, herbicides, and less than optimal nutrients, moisture, and temperature levels can also affect allelopathic weed suppression. Different plant parts can also have allelopathic activity that varies over a growing season and include flowers, leaves, leaf litter and leaf mulch, stems, bark, root, soil and soil leachates and their derived compounds. Allelochemicals can also persist in the soil, affecting both neighbouring plants as well as those planted in succession (Ferguson & Rathinasabathi, 2003). Sanford & Hairston (1984) reported that phytotoxic and allelopathic effects of different crop residues could also affect crop yields.

El-Khawas & Shehata (2005) found that seedling emergence was reduced with treatment of *Acacia nilotica* and *Eucalyptus rostrata* on morphological, biological and molecular criteria of maize and kidney pea. Recent yield declines in cropping systems has been attributed to allelopathic effects (El-Khawas & Shehata, 2005). These allelopathy associated problems have been observed both in monocultures and multiple cropping systems. Continuous monoculture causes the accumulation of phytotoxins and harmful microbes in the soil that give rise to phytotoxicity and reduced soil fertility. A number of weed species possesses allelopathic properties, which have growth inhibiting effects on crops. Allelocompounds inhibiting plant growth affect many physiological processes, among others, the effect of ion uptake and hydraulic conductivity (water uptake) are particularly important. Since the root is the first organ to come into contact with the allelochemicals in the rhizosphere the degree of inhibition depends on their concentration (Blum, Shafer & Lenman, 1999). Some plants are able to escape allelopathic chemical(s) due to their "hypersensitivity" i.e. some plant root tips become strongly affected by allelochemical(s), which can inhibit growth (Chon *et al*., 2002).

1.2.6. Pests and diseases in intercropping

Maize is susceptible to many insects such as weevils, beetle**s**, bollworms, stalk borers and chilo borers and the ones that suck plant sap such as leafhoppers and maize aphids (Drinwater *et al*., 2002). Diseases such as bacterial (stalk rot and leaf streak), viral (dwarf mosaic and streak diseases) and fungal (cob and tassel smut) are common infectious diseases including maize root knot nematodes (Flett *et al*., 1996). Cowpea is normally affected by insects such as aphids, foliage beetles, thrips and legume pod borers (Adipala *et al*., 1999). Diseases such as rusts, viral diseases (e.g. athracnose) and scab are also important including bacterial disease such as blight (Edema, 1995).

When species are grown as sole crops it attracts many pests and diseases, which visually might show less damage when intercropped compared to monoculture (Trenbath, 1993). This may be related to microenvironment effects of associated crops in intercropping compared to sole cropping (Vandermeer, 1989; Letourneau, 1990). Thus, depending on the crop, the attack may affect resource capture, resource conversion efficiency or harvest index (HI) through attacking of leaves, flowers, flower buds and fruits hence upsetting the source-sink relationship and phenology (Baker & Yusaf, 1976; Crawley, 1989). Various integrated pest management (IPM) control strategies such as the use of cultural, biological and chemical methods are also being used for insect pest control. Root (1973) stated that pests find it very difficult to find their hosts because of visual disturbance for their search pattern and tend to stay for shorter times because of disruptive effect of landing on non-host plants resulting in slow survival. Even the presence of weeds can similarly affect pest search for their hosts (Altieri, Glaser & Schmidt, 1990).

Breeding of cereal cultivars resistant to diseases has also been used in intercropping to control airborne diseases of rapidly evolving specialized fungal diseases such as rusts and mildews (Wolfe, 1985). Maize leafhopper (*Dalbus maindis*) was significantly reduced from different maize cultivars under intercropping (Power, 1990). This was the same with fungal spores on leaves, root parasitic nematodes (eelworms) intercepted by roots of hosts and non-hosts (Trudgill, 1991). Intercropping the cowpea cultivar PAN 311 also reduced stalk borer *Chilo partellus* (Swinhoe) infestation significantly in sorghum compared to sole crop (Ayisi & Mposi, 2001). Bean yield was found to be reduced by intercropping as well as aphid attack (Ogenga-Latigo, Ampofo & Baliddawa, 1992a,b). Thus, when yield is reduced due to diseases and pests attack LER is also reduced (Kass, 1978).

The variability of insect pest control and yield improvement in intercropping systems relative to sole cropping have been inconsistent over habits, component species, varieties, density, row arrangement, soil fertility and moisture (Ayisi & Mposi, 2001) and individual crops may not respond the same (Nwanze & Mueller, 1989). Maize stem borer was found to be more severe under sole cropping than intercropping with lablab [*Lablab purpureus* (L)] (Maluleke, Addo-Bediako & Ayisi, 2005). Higher plant densities were also reported to reduce aphid infestation under intercropping and there was a possibility that low viral disease(s) under these conditions were due to unfavorable microclimate for the aphids in intercrops (Ogenga-Latigo *et al*., 1992a,b).

1.3. Biological Nitrogen Fixation (BNF) in legume-cereal cropping systems

N_2, which occurs in the atmosphere and released through decomposition of organic material, is converted to ammonia by the process of BNF. This process is done through *rhizobial* fixation in legumes by free-living diazotrophs. Ammonia is further converted by oxidation or reduction to the forms NO_3^--N and NH_4^+-N respectively, which are available to plants (Zahran, 1999). The plant furnishes the necessary energy that enables the bacteria to fix gaseous N_2 from the atmosphere and pass it on to the plant for use in producing protein. This partnership is known as symbiotic N fixation (Adjei, Quesenberry and Chambliss, 2006). BNF by legumes is a key process in Low External Input Agriculture (LEIA) technologies as it potentially results in a net addition of N to the system. However, the quantity of N fixed by legumes is difficult to quantify and varies according to the species involved and the location (Webster &

Wilson, 1998).

Since 1973 to 1988 the average global consumption of N-fertilizer has increased from 8 to 17 kg N ha^{-1} for agricultural purposes (FAO, 1990) and this significant increase has occurred in both developing and developed countries (Peoples *et al.*, 1995b). The requirements for fertilizer N are predicted to increase in future (Subba-Rao, 1980), however, with current technologies for fertilizer application, both economic and ecological costs of fertilizer usage will eventually become prohibitive. For more than 100 years, BNF has attracted the attention of scientists concerned with plant nutrition and it has been exploited extensively in agricultural practice (Dixon & Wheeler, 1986; Burris, 1994). The importance of BNF as a primary source of N for agriculture has diminished in recent decades as the amount of N fertilizer increased for the production of food and cash crops (Park & Buttery, 1989). In recent years, the international emphasis on environmentally sustainable development focuses on the use of renewable resources, which include attention on the potential role of BNF for supplying N for agriculture (Dixon & Wheeler, 1986; Peoples *et al*., 1995b). Currently the subject of BNF is of great practical importance because the use of nitrogenous fertilizers has resulted in unacceptable levels of water pollution (increasing concentrations of toxic nitrates in drinking water supplies) and the eutrophication of lakes and rivers (Dixon & Wheeler, 1986; Sprent & Sprent, 1990 and Al-Sherif, 1998). While BNF may be tailored to the need for organisms, fertilizers are usually applied in a few large dosages, which may be leached (Sprent & Sprent, 1990), resulting in not only a waste of energy and money but also leads to serious pollution problems, particularly in waste supplies.

Nitrogen fixation is an energy demanding process and dependent on photosynthesis (Bach, Mague & Burris, 1958). If the intercrop non-legume is taller than the legume crop, shading will occur and photosynthesis and subsequently N_2-fixation will be reduced (Wahua & Muller, 1978; Trang & Giddens, 1980). Plant density also has an effect on N_2-fixing activity. A reduction in N_2-fixation per plant at increasing plant density has been reported (Hardy & Havelka, 1976), but total N_2-fixing activity per area appeared to be less variable (Hardy & Havelka, 1976). Values compiled by Brady (1990) and Peoples *et al*. (1995) indicate that the rate of N fixation by a range of legumes varies between 5 and 300 kg N ha^{-1} $year^{-1}$, with an average of about 100 kg N ha^{-1} $year^{-1}$. The amount of biologically fixed N_2 that is actually taken up by the main crop is difficult to determine with accuracy. Lindemann & Glover (1996) reported that BNF could take many forms in nature including free-living soil bacteria, which contributes significant quantities of NH_3 to natural ecosystems and that nitrogen fixation by legumes can range between 11 and 34 kg N ha^{-1} $year^{-1}$ in a natural environment and several hundred kilograms in a cropping system. Apart from that, it was also found that seed harvested from the component crops is likely to be the major source of nitrogen loss from the intercrop system and can range from 50 to 150 kg N ha^{-1}. Nitrogen in the system can be lost through harvested material, normally the seed, and through denitrification, leaching and volatilization (Stern, 1993).

1.4. Effects of applied Nitrogen

The application rate of fertilizer N to legumes (5 to 50 kg ha^{-1}) is generally low compared to cereals and cash crops (FAO, 1992; Peoples *et al*., 1995), however, even relatively low levels of soil nitrate are capable of depressing BNF, which is the ability of legumes to convert atmospheric N into a usable form by the plant. Although small amounts of fertilizer N have been reported to stimulate growth and N_2 fixation in some instances (Becker *et al*., 1991; Gibson, Dreyfus & Dommergues, 1982) the use of starter N can jeopardize N_2 fixation inputs in other situations (Jensen, 1987; Peoples *et al*., 1995). Ofori & Stern (1987) reviewed the influence of applied N on various intercropping systems. They found that intercrop cereal yields increased progressively with N application, while seed yield of the legume either decreased or responded less. They concluded that N application did not improve the Land Equivalent Ratio (LER) and, thus, the efficiency of the cereal/legume intercrop system. Because of the inability of cowpea in mixture to derive its entire N from N_2 fixation, Chang & Shibles (1985) attributed this to the shading effect by the cereal crop. They observed that under high fertilization (N, P) mono and mixed cultures obtained the same yields, however, under low fertilization more land planted in monocultures would be needed to produce the same total yield compared to an area of mixed cropping.

Ofori and Stern (1986), in a maize/cowpea intercrop system, observed that the LER decreased with N application increases from 0 to 100 kg N ha^{-1}. The legume, capable of fixing N_2, is thought to compete less with the cereal component for soil N (Trenbath, 1976). Chang & Shibles (1985) and Ofori & Stern (1986) reported strong competition between maize and cowpea for soil N when no N fertilizer was added and strong intraspecific (within the row) competition between maize and cowpea was demonstrated by Ezumah *et al.* (1987). They suggested that inconsistent yields in mixed cropping might be attributed to varying growth habits and plant architectures (Koli, 1975) of component crops or to fertilizer application management (Haizel, 1974). Similarly, Ofori & Stern (1986), in a maize/cowpea intercrop trial, showed that the intercrops produced larger LAI and total dry matter yield than the sole crops without applied N. Large applications result in excessive vegetative growth of the cereal, causing it to shade and suppress the legume's yield. Ofori & Stern (1986), in a maize/cowpea combination, also observed a similar phenomenon when cowpea intercrop seed yield was significantly reduced by 25 kg ha^{-1}.

1.5. Nitrogen transfer in intercropping systems

Conflicting reports exist about the transfer of N from legumes to cereals in intercropping studies. Nitrogen transfer refers to the movement of biologically fixed N from the legume crop to the non-legume crop and encompases interactions within the soil such as, whether it is incorporated into soil organic matter, reduced into a mineral form, directly taken up by the companion crop, or lost from the system, and are affected by physical and biological factors at that time (Stern, 1993). This can either be direct transfer to the companion non-legume crop in the current growing season, or by indirect transfer into the soil and then to the non-legume crop or residually available to the subsequent crops (Ofori & Stern, 1987). The mechanism of transfer depends on the species, proportion of component crops in the stand, relative maturities of the associated crops, and their vigour and duration of growth. Herridge *et al.* (1994) emphasized that a problem faced by farmers everywhere is that the capacity of soils to supply N declines rapidly once agricultural activities commence and N derived from the breakdown of soil organic matter must be supplemented from other sources. To keep up sustainable production, N removed must be replaced by N fertilizers or by BNF (Reeves, Ellington & Brooke, 1984; Strong *et al*., 1986 and Dalal *et al*., 1994).

1.5.1. Direct and indirect N transfer

The movement of fixed N from the legume to the companion crop during the current growing season is referred to as direct N transfer (Stern, 1993). According to Ofori & Stern (1987) and Fujita, Ofusu-Budu & Ogata (1992), an assumption exists stating that a portion of N_2 fixed by an intercropped legume is made available to an associated non-legume crop during the growing season. There is also a belief that *mycorrhiza* can thus help in the direct transfer of N from plant to plant, which depends on the biomass of the legume crop (Stern, 1993). Because intercropping is a one-year duration, Peoples & Herridge (1990), commented that direct transfer of N from legume to non-legume might not be a rapid or spontaneous phenomenon. Ofori, Pate, & Stern (1987) observed no direct transfer from cowpea or rice bean (*Vigna umbellata*) to maize.

When the fixed N becomes subsequently available to the companion non-legume crop during the current season it is referred to as indirect N transfer (Stern, 1993). Decaying of roots and nodules are thought to be an important factor that determines indirect N transfer. Generally, there is a small amount of N transfer during a current season and most movement occurs during the end of the legume crop cycle. Although these organs contain only a fraction of total N (Buresh & De Datta, 1991), the proportion of root system that might be decomposing during growth has not been estimated (Peoples & Craswell, 1992). The possibility also exists that N exudation from roots shouldn't be ignored (Poth, La Farve & Fotch, 1986). Indirect transfer has been reported by Eaglesham *et al*. (1981) and Bandyopadhyay & De (1986), while this was not confirmed by Kumar Rao *et al*. (1987); Ofori *et al*. (1987); Rerkasem & Rerkasem (1988) and Van Kessel & Reoski (1988).

1.5.2. Residual N transfer

The residual N that remains from the previous season and be utilized in the subsequent seasons is referred to as residual N transfer. This is more evident in the case of crop rotation where extra yield is attributed to improved soil structure following legumes (Hearne, 1986), improvement in soil water holding capacity and buffering capacity and increased nutrient availability associated with incorporation legume residues (Buresh & De Datta, 1991). The total amount of N in a legume crop comes either from N_2 fixation or by uptake of mineral N from the soil. Improvement of cereal yields following monocropped legumes lie mainly in the 0.5 to 3 t ha^{-1} range representing around 30 to 350% increases over yields in cereal-cereal cropping sequences. The response to previously intercropped legumes are more modest and yield improvements of only 0.34 to 0.77 t ha^{-1} have been measured (Peoples & Craswell, 1992). More nitrate remaining in the soil following a legume than after a cereal or other non-legume can also have an effect (Herridge & Bergersen, 1988). However, much of the unexpected benefits probably result from the use of cereal-cereal rotation as a “bench-mark” comparison for the performance of legume cereal sequences (Peoples & Craswell, 1992). Effects of annual legumes on soil N are not clearly detected, as inconsistent results were found when legumes were planted prior to cereal crops (Dalal *et al*., 1994 and Strong *et al*., 1986).

1.6. Methods of estimating N_2 fixation

The determination of added N percentage, derived from N_2 fixation, is very important for enhanced BNF. Several methods are outlined of, which the ^{15}N enriched isotope dilution technique and the ^{15}N natural abundance method have been extensively used for estimation of BNF (Somado & Kuehne, 2006). It has been reported by Peoples & Herridge (1990) that there is no single most appropriate method for measuring symbiotic N fixation as each method has its advantages and disadvantages.

1.6.1. Acetylene reduction assay (ARA)

This method involves the incubation of the whole plant or some plant parts in a closed vessel, containing 10% acetylene at a time period of about 0.5- 2 hours. The reduction of N_2 by the nitrogenase enzyme is inhibited and the enzyme reduces acetylene to ethylene, which is measured by gas chromatography. The ARA method is very simple, rapid and sensitive, and relatively low in cost. However, there are some limitations such as a potential of assay on nitrogenase activity. In some legumes there can be a substantial decline in nitrogenase activity within several minutes of commencing the assay, and this can lead to an underestimation of BNF by approximately up to 50% (Ledgard & Steele, 1992).

1.6.2. Total legume nitrogen and nitrogen difference

This is also one of the simplest methods of estimating BNF, however, this method assumes that all the N available in the legume is fixed, which is not true since legumes also use plant-available soil nitrogen, thus overestimating BNF. In soils very low in N, the proportion of legume N fixed from atmospheric N_2 (P_N) is often near 90% (Ledgard, Brier & Littler, 1987). With the nitrogen difference method, the nitrogen in the legume N yield is compared to that in the non-legume crop, especially under intercropping systems and it assumes that the legume and the reference plant absorb the same amount of soil N. Hardy and Holsten (1977) concluded that this method underestimates the N fixation ability of the legume because the legume utilizes less N than the reference plant, thus, resulting in negative estimates of BNF. Evans & Taylor (1987) proposed the more modified equation for N estimation because levels of soil mineral N were invariably higher when following a legume crop than after a non-legume crop.

$$N_2\ fixed = (N_{leg} - N_{nonleg}) + (SoilN_{leg} - SoilN_{nonleg})$$

Where N refers to plant N concentrations in the legumes and non-legumes and soil N to soil N concentrations. With the modified N difference method, more accuracy will be achieved when plant available soil N is low and the legume biomass is high.

1.6.3. ^{15}N isotope dilution

The ^{15}N isotope dilution method is commonly used to describe the differences in ^{15}N enrichment of atmospheric N_2 and soil N, where soil N is labelled by addition of ^{15}N-enriched material. This method, which was reviewed by Chalk (1985) enables estimation of the proportion of legume fixed N from atmospheric N_2 (P_N):

$$P_N = \frac{(\text{atom \% } ^{15}N_{ref} - \text{atom \% } ^{15}N_{legume})}{(\text{atom \% } ^{15}N_{ref} - B)}$$

Where ref is the non-legume plant growing in the same soil as the legume and B is 0.3663, which constitutes the atom % ^{15}N derived from atmospheric N_2. The amount of N fixed is estimated from P_N x legume N yield. Using the ^{15}N dilution method, enriched ^{15}N-fertilizer is applied to both crops and the difference in ^{15}N dilution between the two crops is used to calculate N_2 fixation (Somado & Kuehne, 2006). The main advantage of this method is that it can be used to estimate a time average of P_N and BNF. This method assumes that the legume and the reference plant have the same ratio (R) of N assimilated from the indigenous soil N. The main disadvantage of the method is that, the characteristics of legume and non-legume N uptake may differ.

1.6.4. Natural ^{15}N abundance

This method was reviewed by Shearer and Kohl (1986), and is similar to the ^{15}N isotope dilution method, except that no ^{15}N material is added. It uses small amounts of natural enriched ^{15}N present in the soil, which is uniform over time and with soil depth. Thus, requirements with the ^{15}N isotope dilution method, which needs a legume and a reference plant to have similar N uptake characteristics, is of relative little importance with the ^{15}N natural abundance method. The main limitations with the method are the analytical sensitivity that give rise to errors, as well as the low natural ^{15}N enrichment of the soil (Steele, 1983). However, the validity of ^{15}N dilution and ^{15}N natural abundance methods has been questioned, especially under field conditions (Handley & Scrimgeour, 1997). It has also been found that the ^{15}N dilution method estimates less N_2 fixation than the ^{15}N natural abundance method. Plant N derived from fixation is thus calculated as follows:

$$P_{fix} = \frac{(\delta^{15}N_{nonleg}) - (\delta^{15}N_{leg})}{(\delta^{15}N_{nonleg}) - B}$$

Where $\delta^{15}N$ is the concentration of N in parts per thousand. Almost all transformations in soil result from isotopic fraction and the net effect is often a small increase in the ^{15}N abundance of soil N with atmospheric N_2 (Shearer & Kohl, 1986). Because figures are so small, data are commonly expressed as parts per thousands (% or $\delta^{15}N$) and by definition, the δ^{15} N of air is zero. The $\delta^{15}N$ value of B is a major isotopic fraction during N_2 fixation and is determined by analysis of the $\delta^{15}N$ for the total plant N of the nodulated legume grown in a N-free medium. Isotopic fraction during N_2 fixation is minimal but not zero and should be taken into account when calculating P_{fix} (Peoples *et al*., 1989).

1.7. Choice of cultivar

Substantial evidence exists that the choice of cultivar or species influences potential contributions of fixed N to farming systems (Wani, Rupela & Lee, 1995). Traditionally cowpea is cultivated as an intercrop with crops such as maize and yam (*Dioscorea spp*) and occasionally as a sole crop. Cowpeas are normally intercropped without due consideration for their competitive properties and their response to light and stress (Babalola, 1980). There is a correlation between crop N and N_2 fixation and cultivar or species. Within a species, variation in growth, final N yield and amounts of N_2 fixed may be due to cultivar effects and duration of growth or maturity groups (Hardarson, Zapata & Danso, 1984; Kumar Rao & Dart, 1987 and Duc, Marioti & Amarger, 1988). Depending on the component crops, yield advantages may vary considerably due to several factors, including differences in plant architecture, rooting patterns, competitive advantages and potential nitrogen fixing capacity of the legume. These, in turn, determine the optimum plant population density, time of sowing and amount of fertilizer N (Mandal *et al*., 1990). According to Low & Waddington (1990), between 45 and 60 % of maize produced by small-scale farmers in Southern Africa is intercropped. In the sub-Saharan region, farmers cultivate a number of species under intercropping conditions to ensure successful production since drought, weeds, insects and diseases can destroy some species while others are able to survive.

1.7.1. Cowpea

Results illustrate that different lines of one legume species growing in the same soil can vary considerably in their ability to fix N (Herridge & Danso, 1995). It has been suggested that distinct differences between species in their relative tolerance towards BNF and in their ability to fix N occurs (Hardarson, Zapta & Danso, 1993), however, evidence for this is conflicting (Herridge *et al.*, 1993). It appears that legume species can differ in their reliance upon N_2 fixation for growth, even when accumulating similar amounts of total N and although the ranking of the symbiotic performance of particular species found in one environment or soil type may not apply to other situations (Evans *et al*., 1989; Beck *et al*., 1991and Peoples *et al*., 1994). Research has established that legume N-yield is the major determinant of N_2 fixation, particularly when the levels of soil nitrate are low and adequate numbers of effective r*hizobia* are present in the soil. Yields in these instances are often related to species or cultivar. Within a species, variations in growth, final N-yield and the amounts of N-fixed may be due to cultivar effects (Armstrong, Pate & Unkovich, 1994) and duration of growth (i.e. maturity group). For instance, Peoples *et al*. (1995a) found that in Thailand black gram, green gram and soybean had similar growth patterns (64- 73 days to maturity) but black gram appeared to be better adapted to the environment and fixed 119 kg N ha^{-1} compared to 66 and 57 kg N ha^{-1} for green gram and soybean, respectively. In Australia, green gram fixed 21 kg N ha^{-1} compared to 254 kg N ha^{-1} from soybean. In terms of growth duration, soybean needed 140 days compared to 95 days of black gram to reach physiological maturity in Australia, meaning a longer growth potential and opportunity for N_2 fixation for soybean. In the same locality, pigeon pea, another long growth duration crop fixed 16 kg N ha^{-1}, indicating the significance of growth duration in BNF.

However, whether a legume is ultimately a net contributor to or net exploiter of soil N will be determined by a cultivar's harvest index for N (Bell *et al*., 1994). Crop variety selection varies by region, depending on several factors including rainfall, and edaphic and socio-economic factors. Crop mixtures may be legume/legume (Rao & Mittra, 1990) or legume/non-legume (Mandal *et al*., 1990). As the maize plant becomes taller than the associated cowpea intercrop, some cultivars mature faster before adverse effects associated with the maize crop become severe, and more often early maturing cultivars are advantageous in intercropping (Ntare, 1989). Watiki *et al*. (1993) found no differences between the yield of maize when different contrasting cowpea cultivars were used and the productivity of intercropping was maximized when high yielding cowpea cultivars were used.

A decrease in grain yield per hactare in legume and cereal was reported by Enyi (1972) when intercropping maize with either cowpea or beans. Besides climatic and environmental factors, water stress appears to be one of the most frequently limiting factors (Masefield, 1952; Kamara, 1976; Sprent, Bradford & Norton, 1977). This results in abscission of 6- 16% of flower buds formed and 37- 55% of open flower development into mature fruits (Adedipe, Fletcher & Ormrod, 1976). The choice of cultivar affects water extraction at different soil depths, leaf area index, stomatal density aperture and behavior to decreased soil water potential, which differs among cultivars. Cowpea variety effect on maize intercropping was significant on soil water extraction but non significant on the performance of maize (Isenmilla, Babalola & Obigbesen, 1981). This must also take into consideration depth of rooting, lateral root spread and root density (Babalola, 1980). Productivity of the intercrop can be enhanced by selection of cultivars suitable for intercropping as they differ in growth durations and habitats and which may result in different interactions when intercropped with maize (Mutungamiri, Mariga & Chivinge, 2001). It has been reported by Arnon (1972) that 98% of cowpea produced in Africa is intercropped.

Besides the study of cereal-legume intercropping stability in most parts of the world such as Brazil (Fraris *et al*., 1983), Nigeria (Norman, 1974) and South Africa (Mpangane *et al*., 2004) there is, however, limited studies on the yield stability of different cowpea cultivars in sole and intercropping systems (Blade *et al*., 1992).

1.7.2. Maize

Instability in maize yield from small-scale farmers is mainly associated with prevailing droughts, declines in soil fertility, choice of intercrop combinations and probably more significant, choice of cultivar (Amede, Bekele & Opondo, 2005). The maize cultivar PAN 6479 is a medium grower of about 62 to 83 days to 50% flowering and 115 to 162 days to physiological maturity in warmer and cooler climates, respectively, and is well adapted to a wide range of environments. In the North West and Free State regions, maize production requires good risk management through the use of lower plant densities and wider row spacing and good moisture conservation practices. Most farmers use PAN 6479 because of its above average yield stability, good agronomic characteristics and its ability to be planted at different planting dates (Pannar, 2007).

Some of the maize characteristics in relation to monocrop and intercropping should be the crop maturity and photoperiod intensity, which is associated with adaptation of a cultivar in relation to planting dates, location and cropping systems. Singh & Chand (1980) reported that maize grain yield was increased from 1.57 to 2.15 t ha^{-1} in sole and intercropping with soybeans, respectively, using the same cultivar. Plant type in terms of height, lodging resistance and canopy that is short and non-lodging are selected for nitrogen responsiveness, with reduced foliage and light competition in crop associations (Francis, Flor & Temple, 1976). Plant population responses as well as uniformity in flowering and maturity are critical in yield determination when two or more crops occupy the same piece of land at the same time. The responses of different maize cultivars under intercropping with different fertility levels also affect their yield potential. Maize cultivars, which minimize intercrop competition and maximize complementary effects, are suitable for intercropping (Rao & Mittra, 1990). Cultivars with short internodes and broad leaves shade legumes relatively more than cultivars of similar height with long internodes and narrow leaves. Tall cultivars generally give more shading to underneath legume crops than short cultivars (Davis & Garcia, 1983).

1.8. Assessment of intercropping productivity

1.8.1. Land Equivalent Ratio (LER)

One of the most important reasons for growing two or more crops simultaneously is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping. An assessment of land return is made from the yield of pure stands and from each separate crop within the mixture. The calculated figure is called the Land Equivalent Ratio (LER), where intercrop yields are divided by the pure stand yields for each crop in the intercropping system and the two figures added together (Mead & Willey, 1980 and Sullivan, 2003).

$$LER = \frac{\text{intercrop maize}}{\text{sole maize}} + \frac{\text{intercrop legume}}{\text{sole legume}}$$

Yield advantages from intercropping, as compared to sole cropping, are often attributed to mutual complementary effects of component crops, such as better total use of available resources. Generally, monoculture legumes have higher yields compared to yields in an intercropping system. However, in most cases, land productivity measured by LER clearly shows the advantage of mixed cropping of cereals and legumes (Mandal *et al*., 1990; Yunusa, 1989). LER gives an indication of magnitude of sole cropping required to produce the same yield on a unit of intercropped land and research results indicate that response of N to intercropping generally results in reduced LER values. In a maize-soybean intercropping system, Ahmed & Rao (1982) reported an LER decrease from 1.64 at 0 kg N application to 1.42 at 85 kg N ha^{-1}. Similar results were also found by Rao & Willey (1980) and Russel & Caldwell (1989) under different levels of nitrogen application. Hiebsch & McCollum (1987) reported that intercropping under low levels of N utilizes the area and time more efficiently than sole crops because of the ability of legumes to fix atmospheric N. However, when two intercrops are using the same growth resource, a decrease in yield of one crop could be expected especially when one crop is more competitive than the other.

Limitations to the use of the LER concept should also be realized, particularly when used to compare the productivity of an intercrop and sole crop. Willey (1979) stated that one major problem is that the computation of LER needs maximum yields of sole crops obtained at optimum plant densities. When yields of sole crops at recommended densities are compared with those of intercrops it will be likely that the advantage of intercropping is overestimated since density may be altered as an experimental variable to determine the optimum density overestimated (Ifenkwe *et al*., 1989). This is most likely to occur in an 'additive' experiment where intercropping of two component crops do have twice the plant density of individual sole crops (Ofori & Stern, 1986). A similar problem occurs when cultivars are tested for their suitability to intercropping. Sole-crop yields of different cultivars may be obtained and partial LER (pLER) values of the component crop be calculated by dividing the yields of a specific cultivar in sole and intercropping production and added together to give total LER. The partial LER gives an indication of the relative competitive abilities of the components of an intercropping system. Thus, the species with higher partial LER is considered to be more competitive for growth limiting factors than the species with lower partial LER (Willey, 1979). However, when sole crop yields differ among cultivars, a higher LER may be obtained compared to cultivars with low sole-crop yields. Thus, for computation of LER the highest yield of a cultivar in sole cropping should be used. This is an illustration that productivity of different cropping systems should be made using treatments, which produce maximum yields for different cropping systems (Fukai, 1993). Another problem is that LER does not give the production of biomass or the exact value of yields, instead, it represents the yield advantage or disadvantages of intercrops compared to sole crops and the time factor is less considered for crop maturities.

1.8.2. Area time equivalent ratio (ATER)

Because the concept of LER does not include a time factor, it seems to over estimate the advantage of intercropping particularly when component crops differ greatly in maturity. The estimation of LER assumes that land occupied by early maturing crops will not be utilized after harvest until harvesting of the late maturing crop. It is very common in intercropping practices that the canopy of late maturing crops would spread to occupy the whole area, but in the case of a sole crop another crop may be planted immediately after the harvest of the early maturing crop (Fukai, 1993). One way to overcome this limitation is by calculating yield production per day as an area time equivalent ratio (ATER) (Hiebsch & McCollum, 1987).

$$ATER = (L_i t_i + L_j t_j)/T$$

Where L_i and L_j are relative yields of partial LER's for component crops i and j, while t_i and t_j are durations (days) for crops i and j, and T is the duration (days) of the whole intercrop system. ATER might, however, under estimate the advantage of intercropping especially when component crops differ in their growth duration. This is because in the semi arid areas it is not possible to plant another crop after harvesting like in the humid tropics where the growing season is continuous. The growing season might not be long enough to have double sole croppings but it may be possible to have a long duration crop. It therefore, appears that in semi-arid areas where double cropping is not possible, LER may be used for comparison, whereas in the humid tropics with continuous growing conditions ATER may be more appropriate (Fukai, 1993).

1.8.3. Staple land equivalent ratio (SLER)

This mostly applies where the primary objective is to get the fixed yield production of one component (staple) crop, which in most cases is a cereal, and some yields of the legume. Reddy and Chetty (1984) proposed an extension of LER to SLER, which is based on the assumption of a basic requirement for minimum supply of a major staple crop such as the cereal.

$$SLER = (Y_i/Y_{ii}) + P_{ij}\,(Y_{ji}/Y_{jj})$$

Where Y_i/Y_{ii} is "the desired standardized yield" of staple i, P_{ij} is the proportion of land devoted to intercropping, and Y_{ji}/Y_{jj} is the relative yield of crop j. This concept has been used partially in India and does not appear to have been used widely else where.

1.8.4. Methods of determining LER

Several methods have been suggested in the literature for calculating LER using different sole crop values and standardised factors. The choice of sole crop yield for standardizing a mixture yield in the estimation of LER consists of averaging all the sole yields in each block (Fisher, 1977); averaging sole yields in the entire experiment (Mead & Stern, 1980; Oyejola & Mead, 1982); averaging sole crop yields at each treatment level in studies that involve graded levels of factor A and B (Mead & Willey, 1980) and using the yield of the best sole crop treatment of each crop (Huxley & Maingu, 1978; Mead & Willey, 1980). These methods cannot be generalized because the method to be used will depend on the aim of the experiment.

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CHAPTER 2: GENERAL MATERIALS AND METHODS

2.1. Sites and soils

Field experiments were conducted during the 2005/06 and 2006/07 growing seasons at the ARC-GCI in the North West Province (Potchefstroom 26^o S; 27^o E) and ARC-SGI in the Free State Province (Bethlehem 28^o S; 28^o E) under rainfed conditions. The soil type at Potchefstroom was a Hutton and at Bethlehem it was of the Avalon form (Macvicar *et al*., 1977). Six soil samples were randomly collected over both trial sites at two depths intervals (0-30 cm for topsoil and 30-60 cm for subsoil) prior to planting. Samples from the relevant depths were combined and sub-samples used to determine soil chemical and physical properties. Soil water content was measured by drying soil samples at 105^{o}C for 72 hours. Dry mass was then determined and the difference between wet mass and dry mass was used to express soil water content on gravimetric basis. Selected chemical and physical analyses, which were done prior to planting, are presented in Table 2.1.

Table 2.1 Pre-plant chemical and physical properties at Potchefstroom and Bethlehem trial sites.

	..……………………Chemical analyses…………………………….		
	Depth (cm)	Bethlehem	Potchefstroom
pH (KCl)	0-30	5.4	6.2
	30-60	5.5	6.5
	…………………………(mg/kg)……………………………….		
P (Bray-1)	0-30	35.6	25.6
	30-60	22.1	10.3
K (Ambic-1)	0-30	72	166.7
	30-60	64	103.2
Ca (Ambic-1)	0-30	409	1655
	30-60	555	1658
Mg (Ambic-1)	0-30	411	546.8
	30-60	539	544
Zn (Ambic- 1)	0-30	4.6	8.6
	30-60	3.2	5.8
NH_4^+ (N)	0-30	0.9	2.2
	30-60	0.8	2.1
NO_3^- (N)	0-30	7.7	3.9
	30-60	5.4	6.5
	……………………………(%)…………………………………….		
N (%)	0-30	0.03	0.1
	30-60	0.04	0.2
	…………………..Physical analyses……………………..………		
Clay (%)	0-30	8.4	31.2
	30-60	10.1	32

2.2. Climate

Potchefstroom is located in the eastern part of the North-West Province with a mean annual rainfall of 640 mm, mean maximum temperature of 25.7 and mean minimum temperature of 10.4 ^{o}C. Bethlehem is located on the eastern part of the Free State Province with mean annual rainfall of about 759.1 mm, mean maximum temperature of 22.7 ^{o}C and 7.7 ^{o}C minimum. Rainfall and temperatures were recorded during the 2005/06 and 2006/07 growing seasons at Potchefstroom and Bethlehem by means of automatic weather stations (Tables 2.2 & 2.3 and figures 2.1 & 2.2).

Table 2.2 Monthly maximum and minimum temperatures (^{o}C) during the 2005/06 and 2006/07 seasons compared with 20 year long-term average at Bethlehem

Months	2005/06 Season		2006/07 Season		Long-term averages	
	Max ^{o}C	Min ^{o}C	Max ^{o}C	Min ^{o}C	Max ^{o}C	Min ^{o}C
October	25.1	9.3	24.8	10.1	23.5	8.6
November	25.9	11.2	24.8	11.3	24.8	10.7
December	27.0	11.6	26.9	13.0	26.2	12.8
January	25.8	14.8	28.2	13.0	27.0	13.8
February	25.1	15.1	29.3	12.7	26.1	13.4
March	22.2	10.9	27.2	10.6	24.7	11.7
April	20.8	7.6	23.7	7.8	22.1	7.6
May	16.1	0.7	20.8	0.1	19.4	2.2
June	17.4	-2.6	16.5	-1.3	16.4	-1.7
July	18.7	-0.6	17.3	-2.9	16.5	-2.1

Table 2.3 Monthly maximum and minimum temperatures (^{o}C) during the 2005/06 and 2006/07 seasons compared with 20 year long-term average at Potchefstroom

Months	2005/06 Season		2006/07 Season		Long-term averages	
	Max ^{o}C	Min ^{o}C	Max ^{o}C	Min ^{o}C	Max ^{o}C	Min ^{o}C
October	29.8	13.2	28.7	12.8	27.6	12.3
November	30.3	14.4	28.4	14.2	28.2	13.9
December	30.3	15.7	29.7	16.5	28.9	15.5
January	27.7	17.7	30.8	16.0	29.3	16.1
February	27.1	17.0	31.2	15.2	28.5	15.7
March	24.8	13.7	29.5	13.2	27.4	13.8
April	23.8	10.2	25.5	10.6	25.3	9.9
May	19.9	2.9	22.8	2.6	22.4	4.7
June	19.9	0.6	19.4	1.2	19.4	1.1
July	21.8	2.9	19.4	0.0	19.5	0.5

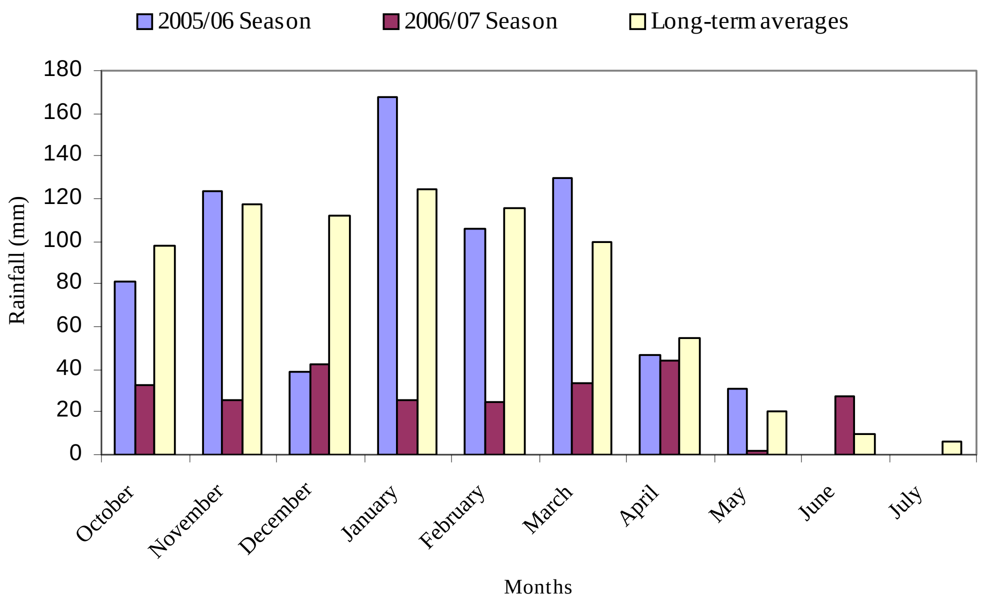

Fig 2.1 Monthly rainfall (mm) during the 2005/06 and 2006/07 seasons compared with 20 year long-term average at Bethlehem.

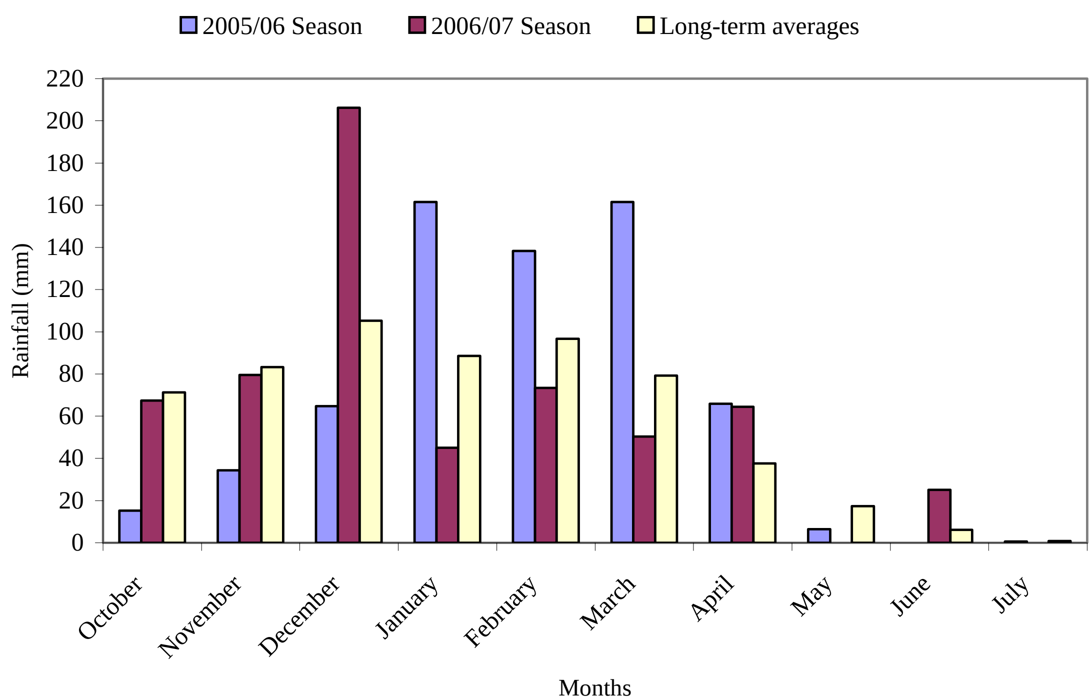

Fig 2.2 Monthly rainfall (mm) during the 2005/06 and 2006/07 seasons compared with 20 year long-term average at Potchefstroom.

2.3. Experimental design and treatments

Each experiment was conducted as a split-plot design based on a randomized complete block design (RCBD) consisting of three replications. The experiment consisted of 14 treatment combinations that were made up from seven cropping systems and two weed infestation levels. Three cowpea cultivars with contrasting growth durations were used: PAN 311 (short duration), Glenda (medium duration) and Agrinawa (long duration) and intercropped with the maize cultivar PAN 6479. In addition, for each cowpea cultivar and the maize cultivar a control treatment (= monocrop) where no intercropping was performed was included. The split-plot was divided into two levels of weed infestation. All the plots were kept weed free for the first month after planting. Thereafter, half of the plots in a random fashion were left for weeds to grow for the remaining part of the growing season, while the other half was kept weed free. At Potchefstroom pre-plant weed control was done with Gramoxone, while at Bethlehem no herbicide was applied because of very low weed infestation levels and weeds were kept at bay using hoes. The density for maize and cowpea were 18 000 plants ha^{-1} and 66 000 plants ha^{-1}, respectively, with a spacing of 1.5 m between the sole plants and 75 cm between intercrops, with four rows of 13 m length per plot. Bethlehem plantings were done on 17th November 2005 and 8th November 2006, while the Potchefstroom trial was planted on 13th of December 2005 and 22nd November 2006. All sole plots were planted mechanically with a Gaspardo pneumatic planter, while the intercrops were planted manually.

Pre-plant nitrogen fertilization was done by broadcasting LAN (28%) at a rate of 10 kg ha^{-1}. Phosphorus was applied in the form of Super-phosphate (MBONAFOS 10.3%) at the rate of 60 kg ha^{-1} for both locations. At Potchefstroom top dressing of maize rows was done at 10 kg ha^{-1} (LAN 28%) approximately four weeks after emergence. All cowpea cultivars were inoculated with Akkerbonepak®50 before planting, which contains a combination of *Rhizobium*, rhizosphere organisms and micronutrients, at the rate of 700ml per 50 kg seed.

Maize stalkborer was controlled manually through application of Kombat (carbaryl/carbamate) at 4 kg ha^{-1} into the plant funnels, using a container with a perforated lid. At harvest in the 2005/06 growing season, soil samples were analyzed for NO_3^+-N and NH_4^--N to determine total nitrogen in the soil as well as for soil water content. Representative samples were collected at all the replicated treatments and replicates then combined to yield fourteen samples. All the samples were taken at 0-30 cm depth with two combined samples per plot.

During the 2006/07 growing season at Potchefstroom, mature maize and cowpea leaf samples were sampled from weed free plots after flowering and samples of *Amaranthus spp* were taken from unweeded plots to determine N content. Samples were oven-dried at 70 ^{o}C for 24 hours and then crushed, using a grinder FRITSCH pulaerisette® Type 1.102. Crushed samples were digested using the micro Kjeldahl digestion (96% Na_2SO_4 and 4% SeO_2) process and N content was determined on the Continuous Flow Auto Analyser (ARC-IIC laboratory). Soil samples were also taken at 0-30 cm depth between the rows in all the plots with ten samples taken at each plot and combined to give a representative sample at both locations. Samples were then analyzed for N concentration through extracting inorganic nitrogen (NH_4-N and NO_3-N in 1 mol dm^{-3} KCL (ARC-IIC laboratory). Statistical analyses were performed for both plant and soil samples using the RCBD method.

2.4. Biomass sampling and measurements

2.4.1. Dry matter

Plant samples were collected at Bethlehem for both maize and cowpea at 56 and 59 days after planting (DAP) for the first sampling. The second sampling was done at 85 and 90 DAP for the 2005/06 and 2006/07 seasons, respectively. At Potchefstroom, the first dry matter was collected at 57 and 58 DAP and the second sampling was done on 87 and 91 DAP for the 2005/06 and 2006/07 seasons, respectively. Plants of the two middle rows were sampled over one meter row length starting at 0.5 m from each row end for both maize and cowpea. The maize plant height was measured and samples were partitioned into leaves and stems, where after DM mass was determined. In addition to dry matter determination leaves were also used for leaf area (LA) measurements, with a leaf area meter (LI-COR model 3100) prior to drying. Leaf area index (LAI) was then determined by dividing LA by total area of sampled plants. Samples were dried at 65^{o}C for 72 hours and dry mass was measured using an electronic scale (Sartorius PMA 7500). Cowpea plant samples were partitioned into the leaf, stem and roots, which were cut from the dug plants at 0.15 m^3 of soil on the cowpea rows for the purpose of nodule count. Pod sheath samples were regarded as part of the stem at first sampling where no pods where formed yet, but at the second sampling mature pods were separated and dealt with as individual plant traits. Nodules were counted for the first cowpea dry matter sampling only. Samples were oven-dried at 65 ^{o}C for 72 hours and dry mass measured using an electronic scale (Sartorius PMA 7500).

2.4.2. Weed sampling

Weed species were sampled randomly in two 0.25 m^2 quadrant areas for the unweeded plots in both locations at 94 DAP at Bethlehem and 95 DAP at Potchefstroom during the 2005/06 growing season. During the 2006/07 growing season, two weed samplings were done, each during the corresponding dry matter sampling period for both maize and cowpea. Weed identification (species), density (number of weed plants per square meter), and dry matter mass were determined. Dry matter was determined by drying weed samples for 72 hours at 65^{o}C, and the dry mass determined by using an electronic scale.

2.4.3. Days to flowering and physiological maturity

Number of days to 50% flowering and physiological maturity were monitored and recorded. Maize physiological maturity was recorded when the black layer at the seed base was observed (Daynard & Duncan, 1969) and cowpea physiological maturity was determined by the change in pod color from green to brown (Cisse & Hall, 2005).

2.4.4. Aboveground biomass at harvest

Aboveground plant biomass was determined by randomly sampling ten cowpea plants and three maize plants per plot. Cobs and pods were segregated and samples were dried at 65 ^{o}C for 72 hours and the dry mass determined. The number of pods per plant for cowpeas and the number of cobs per plant for maize were also counted. The cobs and pods from biomass samples were then added to the harvested pods and cobs.

2.4.5. Yield and yield components

The number of plants harvested was determined when maize was ready to be harvested. At harvest, two middle rows (10 m x 1.5 m) were harvested for both sole and intercropping maize and cowpea plots. Pod (cowpea) and cob (maize) mass was determined by weighing the harvested pods and cobs. Ten pods and ten cobs were then randomly selected to determine pod and cob length and the numbers of seeds per pod (cob) were counted. Grain yield was determined by total seed mass after threshing. The 100 seed mass and the moisture content were also determined. Percent moisture was taken after threshing using the Moisture System 6030 SAT.UNIT.C6. Yields were calculated at 12.5% moisture content. The Land Equivalent Ratio (LER) was determined as outlined by Mead and Willey (1980).

2.5. Data analysis

Data were subjected to analysis of variance (ANOVA), using the program Statistix Version 8.1 (Table 2.2). The differences between the treatment means were separated using the least significant differences (LSD) procedure.

Table 2.2 Typical analysis of variance (ANOVA) table for the treatments

Source	**MC**	**M**	**C**
	DF	**DF**	**DF**
Rep	2	2	2
Weed	1	1	1
Error (1)	2	2	2
Treatment	6	3	5
Treatment x Weed	6	3	5
Error (2)	24	13	20
Total	**41**	**24**	**35**

M= Maize
C= Cowpea
MC= Maize/Cowpea Intercropping

CHAPTER 3: EFFECTS OF INTERCROPPING ON VEGETATIVE GROWTH PARAMETERS OF MAIZE, COWPEA AND WEEDS

3.1. Introduction

Intercropping maize with legumes, mainly cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogeae*) and bamabara groundnut (*Vigna subterranean*) is common among South African smallholder farmers, especially in the Limpopo Province (Maluleke *et al*., 2005). Intercropping affects the vegetative growth of both component crops compared to sole cropping, and therefore, is applied to optimise the use of spatial, temporal and physical resources both above-and belowground with maximum positive and minimum negative interactions (Jose *et al*., 2000 and Silwana & Lucas, 2002). Maize and cowpea are often planted together under intercropping and develop root systems that at the same time explore the same soil for resources (Horwith, 1984; Reddy *et al*., 1994 and Jensen *et al*., 2003). Inter-specific competition during intercropping results in the harmful effect on one crop (Nel, 1975 and Connolly, Goma & Rahim, 2001) and of which, most interactions occur in the rhizosphere of crop mixtures (Zhang, *et al*., 2003, 2004).

Differences in phenological and morphological characteristics of crop species in mixtures may lead to an increased capture of growth-limiting resources (Silwana & Lucas, 2002) leading to greater potential to acquire higher total yields than when crops are grown separately on the same area of land (Rao & Mathuva, 2000; Olufemi, Pitan & Odebiyi, 2001 and Dapaah *et al*., 2003). A competitive main crop such as maize may reduce cowpea growth, and hence Biological Nitrogen Fixation (BNF) rates in an intercrop that results in the reduction of dry matter yield and N-fixing nodules on the legume crop due to shading (Shumba, Dhilwayo & Mukoko, 1990; Kumwenda *et al*., 1997 and Jeranyama *et al*., 2000). Fujita, Ofusu-Budu & Ogata (1992) reported that there is a variation in BNF among legumes in both sole and intercropping conditions. However, Fujita *et al.* (1990) and Hardarson & Atkins (2003) reported that competition between the two component crops under intercropping might in turn stimulate N_2-fixation of the legume crops when the cereal demands more N, thus forcing more N_2-fixation.

Plant growth and biomass partitioning results from high Photosynthetic Active Radiation (PAR) interception, thus determining the rate of dry matter accumulation in crops (Monteith, 1977). Solar radiation is one of the major resources determining growth and yield of component crops when planted simultaneously and together, especially when other resources are not limiting plant growth (Watiki *et al.*, 1993). According to Silwana & Lucas (2002), plant height of maize intercropped with both beans and pumpkin were adversely affected by intercropping conditions. Maize plants were taller for sole crops compared to when intercropped with beans, both in the presence and absence of weed infestation. According to Akobundu (1993), on average, maize and beans on unweeded plots were 17% taller than those in weeded plots due to competition for light between crops and weeds. Beans intercropped with maize also adversely reduced plant height of maize, compared to sole cropping. As maize density reduced under intercropping and bean density increased, reduced maize plant height and increased plant height for beans were observed. This was similar for both weeded and unweeded plots. When the maize plant becomes taller than the associated cowpeas under intercropping, radiation becomes less available to the cowpeas.

Different planting dates of component crops are said to improve the utilization of resources and minimize competition (Andrews, 1972). However, no advantage was found by late planting of cowpea compared to simultaneous planting with maize (Francis, Prager & Tejada, 1982). According to Maluleke *et al.* (2005) lablab dry matter increased with increasing planting density under intercropping and maize dry matter was reduced with increasing lablab population of 6-10 plants m^{-1}. Prasad & Brook (2005) reported that maize density had a significant effect on LAI, which increased with increasing plant density. LAI of sole maize did not differ significantly from that of maize intercropped with soybean at the same density, indicating no effect by the presence of soybean. LAI of soybean was highest at the lowest maize density compared to other densities and it was always lower under intercropping compared to sole cropping. Higher LAI results in better ground cover for lesser soil water evaporation and weed suppression. Maize leaf status at silking and post anthesis may influence dry matter yield and dry matter content under conditions of drought stress, thereby affecting harvesting time. Hussain *et al.* (2003) found that maize intercropping with different legume species delayed the period to earing and silking, compared to sole cropping.

Isenmilla, Babalola & Obigbesan (1981) reported that the yield of cowpea under intercropping could be improved by 20% through proper choice of cultivar. This is because different cultivars respond differently to intercropping conditions. Cultivars with spreading growth patterns sustain yield reduction better than the semi-erect and erect cultivars. Short duration cowpea cultivars are highly determinate and better adapted to soil conditions with low soil water holding capacity and environments with low rainfall compared to long duration cultivars. Short duration cowpea cultivars do better under intercropping conditions as they mature faster and largely escape the shading effect by the cereal component. It further does not compete with the maize crop for the better part of the life cycle compared to medium and long duration cultivars and thus the maize yield potential is maintained (Pandey & Ngarm, 1985 and Ntare, 1989). Medium and long duration cultivars are well adapted in areas with long growing seasons and have tolerance to excessive moisture and drought (Singh *et al*., 1983) and offers better weed control. Number of days to flowering and maturity, photosynthesis rate and photoperiod are also affected by intercropping conditions (Ellis *et al*., 1984). The availability of photo-assimilates is reduced by low light intensity and shading during flowering, which causes abortion of flower initials (Rao & Mittra, 1994). The introduction of different cowpea cultivars of different growth duration and habits into the system is viable since most small scale farmers are familiar with the intercropping concept (Nnadi & Haque, 1986) as well as the response of weeds to the smothering effect of high crop density coupled with intensive shading.

Plant growth is restricted at very high and very low moisture levels. Moisture stress causes reduction in cell division and elongation and thereby influences growth and has a direct relationship with nutrient uptake by the plants. When moisture supply is adequate, an increase in nutrient uptake increases the water efficiency of plants. Low moisture levels reduce activity of microorganisms and result in lower availability of nitrogen supply (Metcalfe & Elkins, 1980). Under intercropping, when water is a limiting factor, crops compete for water and thus result in inhibited growth and low yield due to insufficient nutrient supply.

In addition to intercropping, competition from weed infestation may be reduced by incorporating different crop species that occupy two or more niches in the same field (Altieri & Liebman, 1986). The performance of intercropping activity can be enhanced by low N (Hiebsch & McCollum, 1987) and low weed competition (Ayeni, Duke & Akobundu, 1984). Intercropping maize with groundnut, mungbean or sweet potato reduces weed growth i.e. dry matter and density of species, yield loses and time required for weeding (Steiner, 1984). The introduction of maize/cowpea mixtures for vegetative yield is associated with livestock feed and soil nutrient improvement, with cowpea serving as green manure for the promotion crop yields and herbage quality (Nnadi & Haque, 1986). Thus, more legumes integrated into maize cropping systems are important since most small-scale farmers reject the growing of sole legumes (Jeranyama *et al.*, 2000).

The aim of this component of the study was to investigate the effects of intercropping different cowpea cultivars with maize on maize, cowpea and weed vegetative growth parameters.

3.2. Materials and methods

The materials and methods employed are presented in Chapter 2.

3.3. Results and discussion

3.3.1. Effect of cropping system on maize growth parameters

3.3.1.1. Leaf area index (LAI)

Significant differences between LAI means for cropping system were observed at Bethlehem during the 2005/06 season (Table 1- Appendix A). Maize intercropped with Agrinawa had a significantly higher LAI (2.23) compared to the short and medium season cowpea cultivars (Table 3.1). This implies that maize LAI was affected by the intercropping system for that specific season. No significant differences were observed during the 2006/07 season at Bethlehem and the mean LAI was 0.83 (Table 3.1). No significant differences in LAI were observed at Potchefstroom between the treatment means for the 2005/06 and 2006/07 seasons. At Bethlehem and Potchefstroom, the maize LAI was 59 and 53%, lower in the second season, compared to the first season indicating the significance of seasonal variation. This was as a result of higher temperatures during the mid vegetative growth stage and lower rainfall during the 2006/07 season compared to the 2005/06 season (Table 2.2 & 2.3), which could have resulted in high evaporation and more competition for water between the crops. Nevertheless, environmental factors such as limited moisture, influences the leaf area development (Afuakwa & Crookston, 1984).

Table 3.1 Effect of cropping system on maize leaf area index (LAI) at Bethlehem for the 2005/06 and 2006/07 growing seasons.

Locality	Cropping System	Growth season		Mean
Bethlehem		2005/06	2006/07	
	Maize Mono	2.1533ab	0.9624a	1.5578a
	Maize+PAN311	1.9054bc	0.7866ab	1.3460b
	Maize+Glenda	1.8503c	0.8098ab	1.3300b
	Maize+Agrinawa	2.2293a	0.7460b	1.4876ab
	Mean	2.0346	0.8262	

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

The absence of significant differences could be attributed to low rainfall distribution in the second season, which could have hindered growth and development of the plant. High maximum temperatures in the second season at both locations could also have resulted in higher soil moisture evaporation and transpiration from the plants, which retarded plant growth in that season (Tables 2.2 & 2.3). Intercropping of cowpea, and especially the longer season growers, with maize may, therefore, had an adverse effect on LAI of maize. This effect will probably be more pronounced in seasons with high temperatures and lower rainfall. These results are similar to those of Zegada-Lizarazu, Izumi & Iijima (2006) who found that intercropping reduced pearl millet LAI compared to sole cropping. Higher maize LAI when intercropped with Agrinawa during the 2005/06 season could have been attributed to sufficient rainfall that stimulated maize leaf growth. During the drier season of 2006/07, the long duration cowpea cultivar (Agrinawa) competed stronger with maize for water and nutrients due to longer growth cycle, which resulted in reduced leaf area development of maize. In contrast to this, especially the short duration grower had a better chance to succeed because of a shorter growth cycle and thus less influence on maize. Bilalis *et al.* (2005), found that maize monocrop had the highest LAI (2.52) compared to maize intercropped with cowpea and beans (LAI's 2.12 and 2.44, respectively). The absence of differences in maize LAI between all treatments at Potchefstroom correspond with results of Filho (2000) who did not find any significant differences between sole maize and maize intercropped with cowpea. Twala & Ossom (2004) also did not find any significant differences in LAI between maize monocrop and maize intercropped with sugar beans or groundnuts. This means that cowpea growth duration and weed infestation effects did not affect the leaf growth of the maize crop. These opposing but also corresponding results support the fact that different climatic seasons will result in different leaf development patterns of maize, with or without intercropping. Over the locations, maize at Bethlehem gave a total of 21% higher LAI on average than maize at Potchefstroom, making the former a more suitable locality for leaf area development.

From the results it can be concluded that maize LAI was not affected by cowpea cultivars of different growth duration in areas of high temperatures and low annual rainfall, whereas in cooler temperature and higher rainfall regions, maize LAI responds to different growth duration cowpea cultivars.

3.3.1.2. Total dry matter yield (DMY)

During both seasons at both localities, no significant effects were observed (Table 1-Appendix A) but maize at Bethlehem produced a mean of 6 294.6 and 4 052.1 kg ha^{-1} over the two seasons and maize at Potchefstroom produced 4 067.7 and 3 343.3 kg ha^{-1} for 2005/06 and 2006/07 seasons, respectively. Total DMY in the second season was 35 and 17% lower compared to the first season at Bethlehem and Potchefstroom, respectively. Generally, maize at Bethlehem produced 39% more total DMY than maize at Potchefstroom.

3.3.1.3. Plant height

Treatment effects did not affect plant height during both seasons at Bethlehem and during the 2005/06 season at Potchefstroom while only the main effect for cropping system was significant for the 2006/07 season at Potchefstroom (Table 1-Appendix A). The mean plant height for Bethlehem was 213.30 and 197.82 cm during the 2005/06 and 2006/07 seasons, respectively. At Potchefstroom the mean height was 223.45 cm during the 2005/06 season. During the 2006/07 season maize monocrop had the tallest plants (226.13 cm) at Potchefstroom, compared to maize intercropped with PAN311 and Agrinawa, which had the lowest (206.10 and 194.98 cm, respectively) plant heights (Table 3.2). These results are similar to those of Silwana &

Lucas (2002) who found that maize monocrop was taller than intercropping with beans both in the absence and presence of weeds. In other results, Thwala & Ossom (2004) did not find any significant differences between maize monocrop and intercropping with sugar beans and groundnuts. Similarly, Watiki *et al.* (1993) found that maize intercropped with different cowpea cultivars does not have any effect on maize plant height. Over the two seasons, plant height was found to be higher at Potchefstroom (216.51 cm) compared to Bethlehem (207.06 cm). During the second season, plant height was 8% lower at Bethlehem, while it was 6% lower at Potchefstroom.

Table 3.2 Effect of cropping system on maize plant height (cm) at Potchefstroom for the 2005/06 and 2006/07 growing seasons.

Locality	Cropping System	Growth season		Mean
Potchefstroom		2005/06	2006/07	
	Maize Mono	226.23a	226.13a	226.18a
	Maize + PAN311	218.95b	206.10b	212.53b
	Maize + Glenda	223.20ab	211.12ab	217.16ab
	Maize + Agrinawa	225.45a	194.98b	210.22b
	Mean	223.45	209.58	

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

Cowpea intercropping reduced plant height of maize compared to maize monocrop, especially under water limiting conditions depending on the season. This might be because of the dry season (2006/07) at Potchefstroom, where competition for water was very high and the legume intercrop restricted maize growth. This finding is supported by the results of Allen & Obura (1983). Hussain *et al*. (2003) found that maize plant height was increased by N fertilizer application but reduced by intercropping with different legume species. Mohammed *et al*. (2008) reported no significant differences on sorghum plant height as affected by cowpea genotype. However, the taller maize plants provide a better advantage of trapping more solar radiation than the intercropped legumes, which is very critical for the growth and development of the crop (Thwala & Ossom, 2004).

3.3.1.4. Number of days to 50% flowering

Treatment effects did not affect the number of days to 50%-flowering during both seasons at both locations (Table 1- Appendix A). On average, maize plants took 75 days to 50%-flowering at Bethlehem and approximately 70 days at Potchefstroom.

3.3.1.5. Number of days to physiological maturity

At Bethlehem, significant effects for cropping system and weed infestation during the 2005/06, and weed infestation during the 2006/07 season, were observed (Table 1- Appendix A). During the 2005/06 growing season, maize monocrop took longer (159 days) to mature than maize intercropped with different cowpea cultivars (Table 3.3). Intercropping reduced number of days to physiological maturity of intercropped maize during both seasons, as did weed infestation. During the 2005/06 and 2006/07 growing seasons, in the absence of weeds, maize monocrop took 161 days, compared to maize with weed infestation where it took 156 to 157 days. These results are different from those of Ugen & Wien (1996) who reported that sole maize tasseled and matured earlier than maize intercropped with beans. This was attributed to early intraspecific competition in maize-bean intercropping compared to intraspecific competition in sole maize. Wahua (1983) mentioned that when component crops compete for nutrients, the development and productivity of resources might be delayed. Thus, low soil N levels reduced growth and eventual tasseling (Ugen & Wien, 1996).

At Potchefstroom during both seasons, the main effects of cropping system and weed infestation were significant (Table 1- Appendix A). During the 2005/06 season, maize monocrop had the longest growth period (121 days) and was not significantly different from maize intercropped with Glenda and Agrinawa, which took 120 and 121 days to maturity (Table 3.3). In the 2006/07 season, maize intercropped with Glenda and Agrinawa had the longest growth period (120 and 120 days, respectively) and maize intercropped with PAN311 had the shortest with 119 days. Weed infestation reduced maturity from 122.33 to 119.75 days in the 2005/06 season and from 120 to 119 days in the 2006/07 season. Without the presence of weeds, maize intercropped with Agrinawa and Glenda, as well as the maize monocrop took the longest number of days while in the presence of weeds no differences were observed.

Maize physiological maturity was significantly reduced by intercropping at Bethlehem, while at Potchefstroom the growth of maize intercropped with only PAN311 was reduced. Weed infestation significantly reduced maize's number of days to maturity at both localities. Water deficit reduces leaf area development and facilitates the formation of a black layer, which determines the physiological maturity of maize. The reduction in number of days to physiological maturity might be attributed to the competition effect for nutrients and especially water, which when in deficit can result in lowered metabolic processes in the plant thus reducing maturity date or time to harvest and yield (Afuakwa & Crookston, 1984). Growth duration of a particular cultivar is highly dependent on its thermal environment and photoperiod, hence, the major determinant of crop yield is its phenology (Rabbinge, van Latesteijn & Goudriaan, 1993).

Table 3.3 The effects of cropping system and weed infestation on physiological maturity of maize for the 2005/06 and 2006/07 seasons at Bethlehem and Potchefstroom.

Bethlehem	Days to physiological maturity		
Cropping System	Weeds	Zero weeds	Mean
	2005/06 Season		
Maize Mono	156.67cd	161.33a	159.00a
Maize + PAN311	155.33d	159.33ab	157.33b
Maize + Glenda	158.00bc	157.33bcd	157.67b
Maize + Agrinawa	156.00cd	158.33bc	157.17b
Mean	156.50b	159.08a	
	2006/07 Season		
Maize Mono	157.33bc	161.00a	159.17a
Maize + PAN311	156.33c	159.00ab	157.67ab
Maize + Glenda	157.67bc	157.33bc	157.50b
Maize + Agrinawa	155.00bc	158.33bc	157.67ab
Mean	157.08b	158.92a	
Potchefstroom			
	2005/06 Season		
Maize Mono	120.33bc	122.67ab	121.50a
Maize + PAN311	119.67c	121.00abc	120.33b
Maize + Glenda	119.33c	122.67ab	121.00a
Maize + Agrinawa	119.67c	123.00a	121.33a
Mean	119.75b	122.33a	
	2006/07 Season		
Cropping System	Weeds	Zero weeds	Mean
Maize Mono	119.00c	122.33abc	119.67bc
Maize + PAN311	119.00c	119.33c	119.17c
Maize + Glenda	120.00bc	121.33ab	120.67a
Maize + Agrinawa	118.67c	122.00a	120.33ab
Mean	119.17b	120.75a	

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

3.3.2. Effect of cropping system on cowpea growth parameters

3.3.2.1. Nodule number per plant

The main effect for cropping system was significant for data from Bethlehem for both seasons (Table 3- Appendix A). During the 2005/06 season, with the exception of Glenda as monocrop, nodule counts of Glenda and Agrinawa, as intercrops, had significantly more nodules per plant (16 and 13, respectively) compared to all other crop treatments (Table 3.4). The same trend was also observed in 2006/07, but only Agrinawa had significantly more nodules (21). In both seasons the short season cowpea cultivar PAN311 had the lowest nodule count, both as monocrop (2-10) and as intercrop (1-16). Weed infestation compared to no-weed plots had no effect on nodule numbers, suggesting that weed occurrence did not affect nodule formation. By comparing the two seasons, with the exception of Glenda, which is a medium season cultivar, all other cowpea treatments yielded more nodules in the 2006/07 season. The 2006/07 season was a much drier season, which suggests that nodule occurrence was favoured by drier and probably warmer soil conditions. Intercropping increased nodule number per plant by 61 and 33% compared to sole cropping systems during the 2005/06 and 2006/07 seasons, respectively (Table 3.4). This, together with the increases in nodule number under drier conditions suggests that mild stress conditions, either through environmental conditions or through crop competition, may stimulate nodule growth.

The number of nodules per plant at Potchefstroom was affected by cropping system during the 2005/06 season and by cropping system and weed infestation during the 2006/07 season (Table 3- Appendix A). During the 2005/06 growing season nodule numbers ranged from 2-9 per plant (Table 3.4). Glenda and Agrinawa sole and intercrops had the highest number of nodules per plant (7, 8, 5 & 7, respectively), while PAN311 as intercrop had the lowest with 2 nodules per plant. Similar to Bethlehem during this season, at Potchefstroom there was a 9% increase in nodule number under intercropping, compared to sole cropping conditions. During the 2006/07 season, Agrinawa and Glenda intercrops had the highest nodule number with three nodules per plant each, while PAN311 and Glenda sole cropping had the lowest with one nodule each per plant. Intercropping increased nodule number per plant by 57% compared to sole cropping in the 2006/07 season and weed infestation reduced nodule number by 28% (Table 3.4). Weeds therefore, affected nodules at

Potchefstroom but not at Bethlehem. This might be due to the competitive effect of weeds during the drier 2006/07 season, which resulted in retarded growth of cowpea plants at Potchefstroom compared to Bethlehem. Under intercropping with zero weed infestation there is no severe competition compared to in the presence of weeds. Intercropping with weed infestation causes more competition and therefore, reduces nodulation unlike intercropping without weeds. This could be as a result of more severe environmental conditions at Potchefstroom that inhibited nodule formation thus resulting in significant nodule reduction under weed infestation.

Tate (1995) reported that *Rhizobium* population densities tend to be lower as moisture stress increases, but become revitalized as moisture stress is relieved. This is because moisture stress changes the plant morphology and induces modification of rhizobial cells, which eventually leads to reduced infection and nodulation of the legume. This however, depends on the growth stage of the plant and it was found that stress during vegetative growth is more detrimental to nodulation and N_2-fixation than during reproductive growth (Albrecht, Bennet & Boote, 1994). According to Kishinevsky, Sen & Weaver (1992), cowpea is one of the legume crops that is highly affected by high soil temperatures that inhibit bacterial infection. This is because high temperatures affect root hair infection, bacteroid differentiation and nodule structure as well as the normal functioning of the legume root nodule.

Generally, cowpea intercropping at Bethlehem increased nodulation by 43% while a 21% increase was observed at Potchefstroom. Similarly, Ayisi & Mpangane (2004) also reported differences in nodule formation among different cowpea cultivars and cropping systems, with long duration cultivars producing heavier nodules than short and medium duration cultivars. Long and medium duration cultivars had higher nodule weight and more weight was found under intercropping than sole cropping. It was concluded that cultivars with consistent nodule weight have higher potential for improving soil fertility through organic matter decomposition (Evans *et al*., 2001). Morgado & Willey (2003) reported that increasing bean population under intercropping increased nodule numbers per plant, which could be as a result of higher competition of maize for available N resources, which could have induced nodulation.

Table 3.4 Effects of cropping system and weed infestation on cowpea number of nodules per plant for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Nodule number per plant		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN 311 Mono	3.867cde	2.367e	3.117c
Glenda Mono	11.000abc	10.733abcd	10.867ab
Agrinawa Mono	9.267bcde	3.533cde	6.400bc
PAN311+ Maize	2.933de	1.767e	2.350c
Glenda+ Maize	18.200a	15.167ab	16.683a
Agrinawa+ Maize	12.667ab	15.067ab	13.867a
Mean	9.6556a	8.1056a	8.8806
	2006/07 Growing season		
PAN 311 Mono	8.467d	10.033cd	9.250c
Glenda Mono	12.833bcd	10.533cd	11.683bc
Agrinawa Mono	15.567abcd	13.067bcd	14.317b
PAN311+ Maize	10.500cd	16.467abc	13.483bc
Glenda+ Maize	11.500bcd	13.567bcd	12.533bc
Agrinawa+ Maize	23.067a	19.100ab	21.083a
Mean	13.656a	13.794a	13.725
Potchefstroom			
	2005/06 Growing season		
PAN 311 Mono	4.400bcd	4.900bcd	4.6500bc
Glenda Mono	11.100a	3.200cd	7.1500ab
Agrinawa Mono	6.167bcd	4.267bcd	5.2167abc
PAN311+ Maize	3.433cd	1.933d	2.6833c
Glenda+ Maize	7.567abc	8.900ab	8.2333a
Agrinawa+ Maize	6.733abcd	8.667ab	7.7000ab
Mean	6.5667a	5.3111a	5.9389
	2006/07 Growing season		
PAN 311 Mono	1.6000bc	2.1000bc	1.8500c
Glenda Mono	1.6667bc	1.9333bc	1.8000c
Agrinawa Mono	1.9667bc	2.1000bc	2.0333ab
PAN311+ Maize	1.4000c	2.6333bc	2.0167bc
Glenda+ Maize	3.3000b	2.7667bc	3.0333ab
Agrinawa+ Maize	2.2333bc	5.5333a	3.8833a
Mean	2.0278b	2.8444a	2.4361

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

This differs from the results of Bayne, Brown & Bethlenfalvay (1984) and Patra & Poi (1998) who reported that maize shading the legumes under intercropping reduced nodule number through shading.

Generally, nodulation was 62% less at Potchefstroom, compared to Bethlehem. This could be attributed to different climatic conditions between the two locations, resulting in different effects on nodulation. Cowpea nodule production probably differed with different cultivars and locality as a result of variable responses to different growing conditions between the two locations. Short duration cultivars produced fewer nodules, probably because of less growth duration than the medium and long duration cultivars. Effective nodulation of the legume plant is generally indicated by vigorous and improved growth (Adjei *et al*., 2006). Early flowering, therefore, favours reproductive growth rather than vegetative growth, thus affecting nodule formation. The lack of efficient *Rhizobium* bacteria in the soil, poor plant nutrition and other biotic or abiotic plant stresses result in poor plant nodulation (Lindeman & Glover, 1996). This could have been the case with the two locations involved, since no intercropping or legume-cropping systems were practiced on the sites before.

3.3.2.2. Cowpea leaf dry matter yield

At Bethlehem during the 2005/06 season, leaf dry matter was significantly affected by cropping system, while this effect, the weed infestation effect and the interaction effect was significant for the 2006/07 season (Table 3- Appendix A). During the 2005/06 season, long and medium growth duration cowpea cultivars Agrinawa and Glenda as monocrop had the highest leaf yield (1634.5 and 1411.8 kg ha^{-1}, respectively) and was reduced to 1 127.4 and 584.2 kg ha^{-1} under intercropping conditions (Table 3.5). Short and medium duration cultivars, PAN311 monocrop and intercrop, and Glenda intercrop had significantly lower leaf yields than the other treatments. During this season, intercropping reduced leaf dry matter yield by 45%, compared to sole cropping and no weed infestation effect was observed between cropping systems. In the absence of weeds during the 2006/07 season, Agrinawa monocrop had the highest yield (1 245.3 kg ha^{-1}), which was reduced to 352.2 kg ha^{-1} under weed infestation. Under intercropping conditions, Agrinawa yielded 668.9 kg ha^{-1} in the presence of weeds, which was reduced to 576.5 kg ha^{-1} in the absence of weeds. PAN311 monocrop and intercrop had the lowest yield, both in the absence and presence of weeds. Generally, medium and long duration cowpea cultivars had significantly higher leaf dry matter yield than short duration cultivars. Weed infestation caused significant (17%) reductions in leaf yield in the 2006/07 season

(Table 3.5). There was a reduction in leaf production in the second season compared to the first season, indicating the significance of seasonal variation at each location. The leaves are the main source of evapotranspiration and the plant therefore, tends to reduce its leaf growth under limited water conditions to minimize water loss (Afuakwa & Crookston, 1984).

At Potchefstroom for both seasons the effects of cropping system, weed infestation and the interaction were significant (Table 3- Appendix A). Similarly to Bethlehem, in 2005/06, the long duration cowpea cultivar Agrinawa monocrop had the highest leaf dry matter yield in the absence of weeds but this was reduced by weed infestation (Table 3.5). PAN311 monocrop and intercrop again had the lowest yield, both in the absence and presence of weeds. Similar trends were also evident during the 2006/07 season. Generally, leaf dry matter yield was significantly reduced by weed infestation, with the exception of Glenda intercrop during the 2005/06 season and Agrinawa intercrop during the 2006/07 season, which were increased by weed infestation. This could be attributed to the response of the cultivars to competition with maize and weeds, which resulted in stimulated growth in especially the leaves. More leaf production will, therefore, ensure that enough photosynthetically active radiation is trapped thus inhibiting weed growth by shading. Adjei *et al*. (2006) indicated that more leaf and total dry matter production also correlates with nodulation of the crop, which is indicated by improved growth. A similar response was found in terms of medium and long duration cowpea cultivars Glenda and Agrinawa, especially under intercropping conditions.

Generally, there was a clear indication at Bethlehem that weed infestation does not affect leaf dry matter yield, except in the case of Agrinawa monocrop, which produced more leaves under no-weed infestation. Significant leaf dry matter reduction was observed at Potchefstroom, with 19% lower yield under weed infestation. On average at both locations, Agrinawa monocrop had the highest yield in the absence of weeds and was reduced by weed infestation. At both locations, the short duration cultivar PAN311 monocrop and intercrop's leaf dry matter remained the lowest both in the presence and absence of weeds. Comparing localities, leaf DMY was 22% higher at Potchefstroom, compared to Bethlehem and intercropping reduced leaf dry matter yield by 38 and 37% at Bethlehem and Potchefstroom, respectively.

Table 3.5 Effect of cowpea cropping system and weed infestation on cowpea leaf dry matter yield for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Leaf dry matter yield (kg ha^{-1})		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN 311 Mono	532.9e	657.2de	595.1c
Glenda Mono	1489.1ab	1334.4ab	1411.8c
Agrinawa Mono	1694.2a	1574.9ab	1634.5a
PAN311+ Maize	271.7e	288.9e	280.3c
Glenda+ Maize	716.6cde	451.7e	584.2c
Agrinawa+ Maize	1186.1abc	1068.6bcd	1127.4b
Mean	981.78a	895.97a	938.87
	2006/07 Growing season		
PAN 311 Mono	239.8e	244.2e	242.02d
Glenda Mono	631.5bc	378.4de	504.95bc
Agrinawa Mono	354.2de	1245.3a	799.78a
PAN311+ Maize	211.2e	213.4e	212.32d
Glenda+ Maize	448.8cd	451.0cd	449.95c
Agrinawa+ Maize	668.9b	576.5bc	622.66b
Mean	425.74b	518.15a	471.94
Potchefstroom			
	2005/06 Growing season		
PAN 311 Mono	661.6de	733.1cde	697.4cd
Glenda Mono	915.3bcd	945.2bc	930.3bc
Agrinawa Mono	1065.3b	2586.6a	1826.0a
PAN311+ Maize	637.0de	454.8e	545.9e
Glenda+ Maize	964.6bc	589.7e	777.1cd
Agrinawa+ Maize	1066.4b	1072.6b	1069.5b
Mean	885.0b	1063.7a	974.35
	2006/07 growing season		
PAN 311 Mono	512.6d	917.5bc	715.1c
Glenda Mono	968.1bc	893.3bc	930.7b
Agrinawa Mono	871.9bc	1883.4a	1377.7a
PAN311+ Maize	369.6d	393.8d	381.7d
Glenda+ Maize	325.2d	348.1d	336.6d
Agrinawa+ Maize	1058.3b	799.8c	929.0b
Mean	684.30b	872.65a	778.47

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

Holderbaum *et al*. (1990) and Sullivan, Perish & Luna (1991) reported that per unit area, intercropping produces more dry matter than sole cropping. From the results it can be concluded that there was a positive interaction between different cowpea treatments and weed infestation on cowpea leaf dry matter yield, especially at

Potchefstroom. Weed infestation, therefore, tends to reduce cowpea leaf dry matter yield, especially under drier conditions.

3.3.3.3. Cowpea total dry matter yield (DMY)

At Bethlehem during the 2005/06 season, total dry matter yield was significantly affected by cropping system, while in the 2006/07 season cropping system and the interaction effect were significant (Table 3- Appendix A). During the 2005/06 growing season, Agrinawa and Glenda monocrop had the highest total dry matter yield (4 490.0 and 4 140.7 kg ha^{-1}, respectively), while PAN311 and Glenda intercrops had the lowest yields (825 and 1 662.3 kg ha^{-1}, respectively) (Table 3.6). During this season, intercropping reduced total dry matter yield by 48%, compared to sole cropping. During the 2006/07 growing season, Agrinawa monocrop gave the highest yield (2 911.1 kg ha^{-1}) at no weed infestation and this was reduced to 1 341.7 kg ha^{-1} under weed infestation. Similar responses were also found at Potchefstroom during both seasons under sole cropping conditions. Under intercropping conditions at Bethlehem, Agrinawa also produced the highest total dry matter yield of 2 293.0 kg ha^{-1}.

During the 2005/06 season at Potchefstroom, cropping system and the interaction effect were significantly different while all the treatment effects in the 2006/07 season were significant (Table 3- Appendix A). During the 2005/06 growing season under intercropping, Agrinawa produced the highest yield (4353.8 kg ha^{-1}) in the absence of weeds, which was reduced to 3428.2 kg ha^{-1} in the presence of weeds (Table 3.6). PAN311 and Glenda intercrops produced the lowest yields (1 984.6 and 2 045.1 kg ha^{-1}, respectively) in the absence of weeds. In the presence of weed, PAN311 sole and intercrop had the lowest yield (2 587.9 and 2 408.4 kg ha^{-1} respectively). During the 2006/07 season, PAN311 and Glenda monocrop and intercrops had the lowest yield in the presence of weeds. Intercropping reduced total DMY by 42% compared to sole cropping, while weed infestation caused 22% reduction.

Table 3.6 Effects of cowpea cropping system and weed infestation on cowpea total dry matter yield for 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Total dry matter yield		
	Weeds	Zero weeds	
Cropping System		2005/06 season	Mean
PAN 311 Mono	1534.4de	2022.9cd	1778.7c
Glenda Mono	4391.2a	3890.2ab	4140.7a
Agrinawa Mono	4399.3a	4580.6a	4490.0a
PAN311+ Maize	837.6e	812.3e	825.0d
Glenda+ Maize	1854.1de	1470.4de	1662.3cd
Agrinawa+ Maize	3152.5bc	2546.3cd	2849.4b
Mean	2694.9a	2553.8a	2624.3
		2006/07 season	
PAN 311 Mono	636.5e	646.0e	641.3c
Glenda Mono	2203.5bc	1895.9cd	2049.7ab
Agrinawa Mono	1341.7d	2911.6a	2126.6ab
PAN311+ Maize	605.1e	681.4e	643.2c
Glenda+ Maize	1859.6cd	2076.1bc	1967.9b
Agrinawa+ Maize	2484.7ab	2101.2bc	2293.0a
Mean	1521.9a	1718.7a	1620.3
Potchefstroom			
		2005/06 season	
PAN 311 Mono	2587.9de	2853.5cd	2720.7cd
Glenda Mono	3417.8c	2889.5cd	3153.7c
Agrinawa Mono	4421.1b	5584.4a	5002.8a
PAN311+ Maize	2408.4de	1984.6e	2196.5d
Glenda+ Maize	2845.5cd	2045.1e	2445.3d
Agrinawa+ Maize	3428.2c	4353.8b	3891.0b
Mean	3184.8a	3285.1a	3234.9
		2006/07 season	
PAN 311 Mono	1485.6def	2365.2bc	1925.4c
Glenda Mono	2076.3bcd	1921.2cde	1998.8bc
Agrinawa Mono	3007.3b	5626.0a	4316.6a
PAN311+ Maize	1098.8ef	1181.3ef	1140.0c
Glenda+ Maize	1039.6f	1134.4ef	1087.0d
Agrinawa+ Maize	2668.9bc	2429.3bc	2549.1b
Mean	1896.1b	2442.9a	2169.5

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

Ayisi & Mpangane (2004) reported that total DMY of cowpea cultivars PAN311 (short duration) and Bechuana white (medium duration), were reduced by 43 and 46%, respectively, under intercropping compared to sole cropping conditions while PAN326 (short duration) and Agrinawa (long duration) were not affected by intercropping conditions. Differences in dry matter yield among different cowpea cultivars were reported and the suppression of legume growth by intercropping was also reported by Clement *et al*. (1992). The short duration cowpea cultivars had the lowest dry matter yield compared to the medium and long duration cultivars. Similar findings were also reported by Ayisi & Mpangane (2004) who found less dry matter yield for short duration cultivars than medium and long duration cultivars. Under intercropping, Agrinawa had the highest dry matter yield with weed infestation at Bethlehem, while the opposite was observed at Potchefstroom. At Potchefstroom, similar to leaf dry matter yield, total dry matter yield was increased by 27% compared to Bethlehem, and intercropping resulted in 32 and 30% reduction at Bethlehem and Potchefstroom, respectively.

3.3.3.4. Number of days to flowering

During both seasons at Bethlehem, cowpea's growth duration to 50%-flowering was significantly affected by cropping system and the interaction effect (Table 3- Appendix A). The same trend on days to 50%-flowering was observed for both seasons at Bethlehem (Table 3.10). In both instances, intercropping resulted in a significant delay in days to 50% flowering of the cowpea cultivars and no differences occurred on average between all weed infested and weed free plots. However, weed infested plots for the short and long seasonal intercropped cowpeas resulted in significant longer duration to 50%-flowering (5- 11 days). Of interest is the behavior of the medium seasonal cultivar Glenda, which took about 25 days longer to reach 50%-flowering under intercropping conditions where no weeds were present. This was observed in both seasons, suggesting that Glenda behave more like a short seasonal cultivar, when cultivated as monocrop and more like a long seasonal cultivar, when cultivated as intercrop. This could be attributed to the microclimate e.g. shading effect of maize, which reduces effective heat unit accumulation and as a result, a longer required growth period. Under small-scale farming systems, where limited land is of significant importance, delayed flowering pertaining to intercropping could cause inconvenience to farmers.

During both seasons at Potchefstroom, there were significant differences among cropping system, weed infestation and the interaction effect (Table 3- Appendix A). In both seasons, intercropping and weed infestation generally resulted in significant delays in number of days to 50%-flowering (Table 3.10). The most significant delays due to intercropping was observed with Agrinawa as intercrop at approximately 11 days during both seasons and PAN311 intercrop with 14 days during 2005/06 season. Weed infestation resulted in 5 and 2 days delay during the first and second season respectively. PAN311 intercrop during the first season and PAN311 monocrop and Agrinawa intercrop during the second season were among the treatments in which 50% flowering was delayed by weed infestation. Again, during both seasons, 50% flowering of Glenda and Agrinawa monocrops were also significantly delayed by weed infestation. This suggests than weed infestation had more influence on 50% flowering of medium and long duration cultivars, especially under monocrop conditions. This is because of the shading of tall growing weeds earlier in the season on required heat units to rich flowering. Again, short duration cultivars grow faster at early growth stage and therefore outgrow weeds-limiting shading. Competition for nutrients and especially water at this locality during both seasons could have triggered significant effects of weed infestation compared to what was observed at Bethlehem. Cowpea cultivars with shorter number of days to flowering and growth such as PAN311 are considered to be well adapted under rainfed conditions because of their ability to sustain drought, especially in the early stages of vegetative growth (Hall, 2004), and for escaping late drought by maturing early.

On average for the two seasons at Bethlehem, no weed infestation effect was observed on 50% flowering, but there was a delay caused by weed infestation at Potchefstroom. Although no weed infestation effect was observed at Bethlehem, Agrinawa mono and intercrop were significantly delayed in the presence of weeds. At Potchefstroom, all the cowpea treatment's growth duration to 50%-flowering were delayed by weed infestation, except for Glenda intercrop, which was not significantly different. This might be an indication that number of days to 50%-flowering is mostly affected by weed infestation under dry environments compared to wetter environments. Intercropping also delayed flowering compared to sole cropping at both locations. This differs from the results of Mpangane *et al.* (2004) who reported no significant differences in terms of flowering and maturity of cowpea cultivars under intercropping. In maize-soybean intercropping, Muoneke, Ogwuche & Kalu (2007) did not find any significant differences on 50% flowering due to cropping system but the differences were observed between the cultivars. According to Summerfield &

Wien (1980) and Hadley *et al*. (1983), flowering is dependent on both genotype and environment and this might be the reason why different cultivars responded differently at each locality.

Table 3.7 Effects of cowpea cropping system and weed infestation on cowpea days to flowering for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Number of days to flowering		
	Weeds	Zero weeds	
Cropping System	2005/06 season		Mean
PAN 311 Mono	59.33g	58.33g	58.83e
Glenda Mono	63.33f	66.67ef	65.00d
Agrinawa Mono	96.33b	87.33d	91.83b
PAN311+ Maize	68.33e	63.33f	65.83d
Glenda+ Maize	69.67e	92.33c	81.00c
Agrinawa+ Maize	105.33a	94.00bc	99.67a
Mean	77.056a	77.000a	
	2006/07 season		
PAN 311 Mono	58.00hi	56.00i	57.00e
Glenda Mono	63.00gh	64.00fg	63.50d
Agrinawa Mono	97.33b	85.00d	91.17b
PAN311+ Maize	70.33e	63.00gh	66.67d
Glenda+ Maize	69.00ef	89.33cd	79.17c
Agrinawa+ Maize	103.33a	92.33bc	97.83a
Mean	76.833a	74.944a	
Potchefstroom			
	2005/06 season		
PAN 311 Mono	53.333fg	50.667g	52.000e
Glenda Mono	62.000d	57.000e	59.500d
Agrinawa Mono	81.333a	69.333b	75.333b
PAN311+ Maize	67.000bc	56.000ef	61.500d
Glenda+ Maize	68.333bc	65.333cd	66.833c
Agrinawa+ Maize	82.667a	79.000a	80.833a
Mean	69.111a	62.889b	
	2006/07 season		
PAN 311 Mono	51.333h	48.333i	49.833f
Glenda Mono	56.000e	54.000f	55.000d
Agrinawa Mono	69.333c	63.000d	66.167b
PAN311+ Maize	52.000gh	53.000fg	52.500e
Glenda+ Maize	63.000d	63.000d	63.000c
Agrinawa+ Maize	79.000a	75.000b	77.000a
Mean	61.778a	59.389b	

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

As mentioned by Rao & Mittra (1994), there is a significant reduction of available photo-assimilates caused by low light intensity and shading especially during flowering, which results in the abortion of some flower initials.

3.3.3.5. Number of days to physiological maturity

At Bethlehem during both seasons, there was a significant difference on cropping system, weed infestation and the interaction effect (Table 3- Appendix A). During both seasons at Bethlehem, weed infestation increased the number of days to physiological maturity while the opposite was observed at Potchefstroom during both seasons (Table 3.8). Although there was a delay caused by weed infestation at Bethlehem, number of days generally ranged from one to two days in the first and second seasons, respectively. Agrinawa and Glenda monocrop were the only treatments where physiological maturity was reduced by weed infestation during both seasons. Under intercropping conditions, all the treatment's number of days to physiological maturity was delayed by weed infestation except for Glenda as intercrop, which did not show any significant difference. Number of days to physiological maturity were generally not affected by intercropping compared to sole cropping conditions.

During both seasons at Potchefstroom, there also were significant differences on cropping system, weed infestation and the interaction effect (Table 3- Appendix A). Weed infestation resulted in approximately 4 and 2 days reduction at Potchefstroom during the first and second season, respectively (Table 3.11). During the 2005/06 season, Glenda monocrop resulted in reduced time to maturity due to weed infestation (109 to 105 days). Under intercropping conditions in both seasons, Glenda and Agrinawa intercrops resulted in significant time reduction to maturity while PAN311 intercrop did not have significant differences between the weed levels during the 2005/06 season. During the 2006/07 season, all the monocrop treatment's days to physiological maturity and PAN311 intercrop were delayed by weed infestation. Generally, at Potchefstroom during both seasons, intercropping significantly delayed days to physiological maturity compared to sole cropping. It can be concluded that intercropping delays physiological maturity under water limited conditions while weed infestation further reduces days to maturity under the same conditions. On average at both locations, contrasting results were observed on the number of days to physiological maturity of the cowpea treatments as affected by weed infestation. At Bethlehem, weed infestation delayed maturity while at Potchefstroom the opposite were observed.

Table 3.8 The effect of cowpea cropping system and weed infestation on cowpea days to physiological maturity during 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Days to physiological maturity		
	Weeds	No weeds	
Cropping System	2005/06 season		Mean
PAN 311 Mono	98.33g	94.00h	96.17c
Glenda Mono	108.00e	111.33d	109.67b
Agrinawa Mono	119.33b	126.67a	123.00a
PAN311+ Maize	102.00f	94.67h	98.33c
Glenda+ Maize	107.00e	108.33e	107.67b
Agrinawa+ Maize	125.00a	116.33c	120.67a
Mean	109.94a	108.56b	
	2006/07 season		
PAN 311 Mono	98.33h	93.00i	95.67e
Glenda Mono	106.00ef	111.00d	108.50c
Agrinawa Mono	118.33b	125.00a	121.67a
PAN311+ Maize	103.00f	95.00h	99.00d
Glenda+ Maize	107.00e	107.00e	107.00c
Agrinawa+ Maize	123.00a	114.67c	118.83a
Mean	109.28a	107.61b	
Potchefstroom			
	2005/06 season		
PAN 311 Mono	92.67fg	90.67g	91.67d
Glenda Mono	105.33d	109.00c	107.17b
Agrinawa Mono	115.00b	114.67b	114.83a
PAN311+ Maize	96.00ef	96.67e	96.33c
Glenda+ Maize	104.00d	116.00b	110.00b
Agrinawa+ Maize	113.00b	121.33a	117.17a
Mean	104.33b	108.06a	
	2006/07 season		
PAN 311 Mono	89.67i	86.33j	88.00e
Glenda Mono	105.33e	102.00f	103.67c
Agrinawa Mono	110.00c	107.67d	108.83b
PAN311+ Maize	96.00g	94.00h	95.00d
Glenda+ Maize	101.00f	118.67a	109.83b
Agrinawa+ Maize	112.00b	117.00a	114.50a
Mean	102.33b	104.28a	

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

At Bethlehem, PAN311 monocrop and intercrop's physiological maturity proved to be delayed by weed infestation while Glenda and Agrinawa monocrops resulted in opposite behavior. Delay to maturity by weed infestation was found to be under intercropping conditions compared to sole cropping. At Potchefstroom under sole cropping conditions only PAN311 monocrop's number of days to physiological maturity was significantly delayed by weed infestation while no differences were observed with Glenda and Agrinawa. Under intercropping conditions, Glenda and Agrinawa as intercrops, were significantly delayed while no differences were observed with PAN311 as intercrop. Delayed physiological maturity by weed infestation at Bethlehem might be because of a tendency of having rainfall especially during cowpea harvest, which delayed crop maturity compared to Potchefstroom. The delay in cowpea flowering under intercropping conditions could have been influenced by the sensitivity of cowpea cultivars to light where there is a reduced day length because of taller maize plants. Therefore resulting in delayed maturity date especially under wetter conditions but the opposite was observed under dry conditions as was influenced by environmental conditions. There were strong correlations between cowpea days to 50% flowering and physiological maturity (Table 3.9).

Table 3.9 Coefficient of determination (r^2) values for cowpea flowering and maturity for 2005/06 and 2006/07 season at Bethlehem and Potchefstroom.

Locality	Growing season		
	2005/06	2006/07	Mean
Bethlehem	0.8220**	0.8040**	0.8168**
Potchefstroom	0.7472**	0.8136**	0.8103**

** = Highly significant

3.3.4. Effect of cropping system on weed dry matter yield (DMY)

At Bethlehem, weed dry matter yield was significantly affected by cropping system in the 2006/07 season (Table 5- Appendix A). In the 2006/07 season, significant more weed DMY was recorded with PAN311 monocrop (1543.4 kg ha^{-1}) and all three maize intercrop treatments had significantly lower yields compared to the monocrop treatments (Fig 3.1). At Bethlehem during the 2006/07 season, maize intercropping with Agrinawa, Glenda and PAN311 reduced weed dry matter yield by 49, 52 and 52%, respectively, compared to sole maize (Fig 3.1). At Bethlehem the weed spectrum was dominated by goose grass (*Eleusine coracana*), common bufallo grass (*Panicum maximun*) and dwarf marigold (*Schkuhria pinnata*).

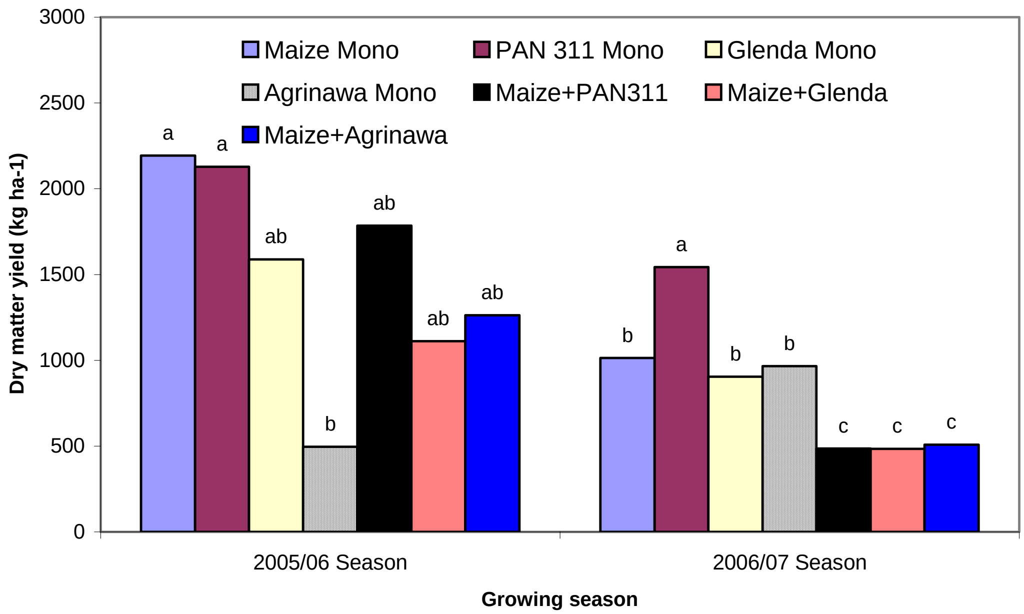

Fig 3.1 Weed dry matter yield (kg ha^{-1}) in the 2005/06 and 2006/07 seasons at Bethlehem.

During both seasons at Potchefstroom, weed DM was significantly affected by cropping system effect. At Potchefstroom during the 2005/06 season, all the intercrop and monocrop treatments were not significantly different from one another, except in the case of PAN311 monocrop, which had significant higher weed DMY (1928.9 kg ha^{-1}) (Fig 3.2). During this season, the long duration cowpea cultivar supressed the weeds better than the short and medium duration cultivars. Maize intercropping with Agrinawa, Glenda and PAN311 reduced weed dry matter by 89, 17 and 15%, respectively, compared to sole maize (Fig 3.2). On average during the 2006/07 season, all cowpea sole crops had the highest weed DMY, while maize intercropped with PAN311 had the lowest (690.6 kg ha^{-1}), which resulted in 38% weed DM reduction compared to sole maize (Fig 3.2).

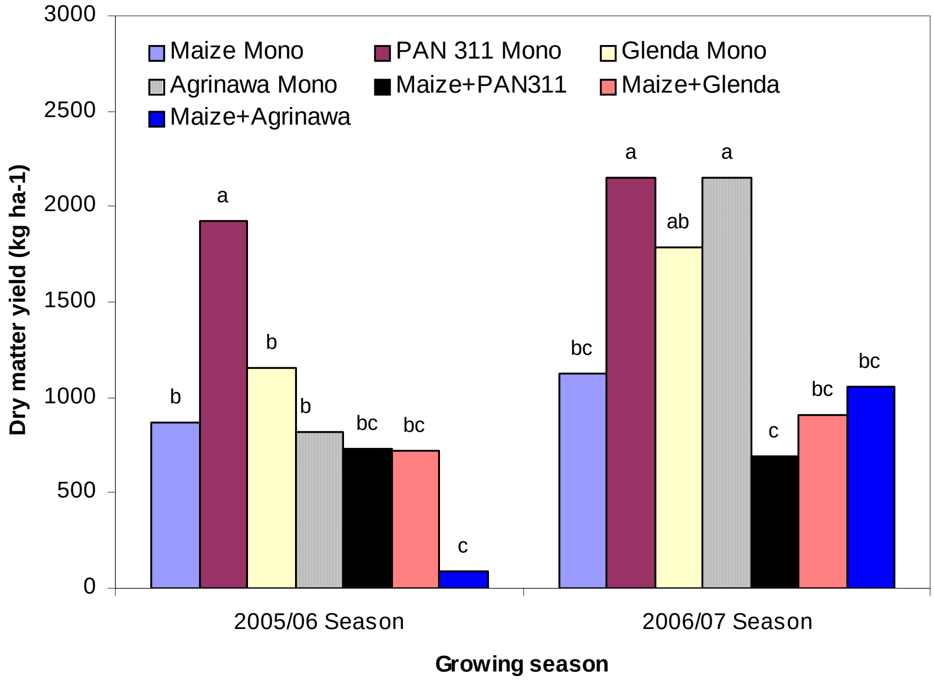

Fig 3.2 Weed dry matter yield (kg ha^{-1}) in the 2005/06 and 2006/07 seasons at Potchefstroom.

The lack of significant weed dry matter reduction between medium and long duration intercrop cultivars and sole maize during the 2006/07 season could be attributed to a very dry season at Potchefstroom, which may have resulted in inhibited growth of these cultivars compared to the short duration cultivar. The weed spectrum at Potchefstroom was dominated by common pigweed (*Amarunthus hybridus*), thorn apple (*Datura stramonium*) and dwarf marigold (*Schkuhria pinnata*).

During the 2006/07 season at Bethlehem, there was more weed DM yield in the first sampling compared to first sampling under both sole and intercropping conditions. This could have been as a result of some late weed species growing better under these specific conditions and the early ones having been more matured thus weighing more (Fig 3.3). Conflicting results to those from Bethlehem were found during the same season at Potchefstroom, first weed DMY was higher than the second sampling under both sole and intercropping treatments, which indicates a significant reduction over time in weeds especially under intercropping (Fig 3.3). This could be attributed to both competitive and allepathic activity of cowpea cultivars to suppress weed growth

(Chung *et al*., 2003; Florentine & Fox, 2003). These differences in weed control between the two locations might be an indication that weed species differ in their responses to different cropping systems, as well as from location to location, and from season to season.

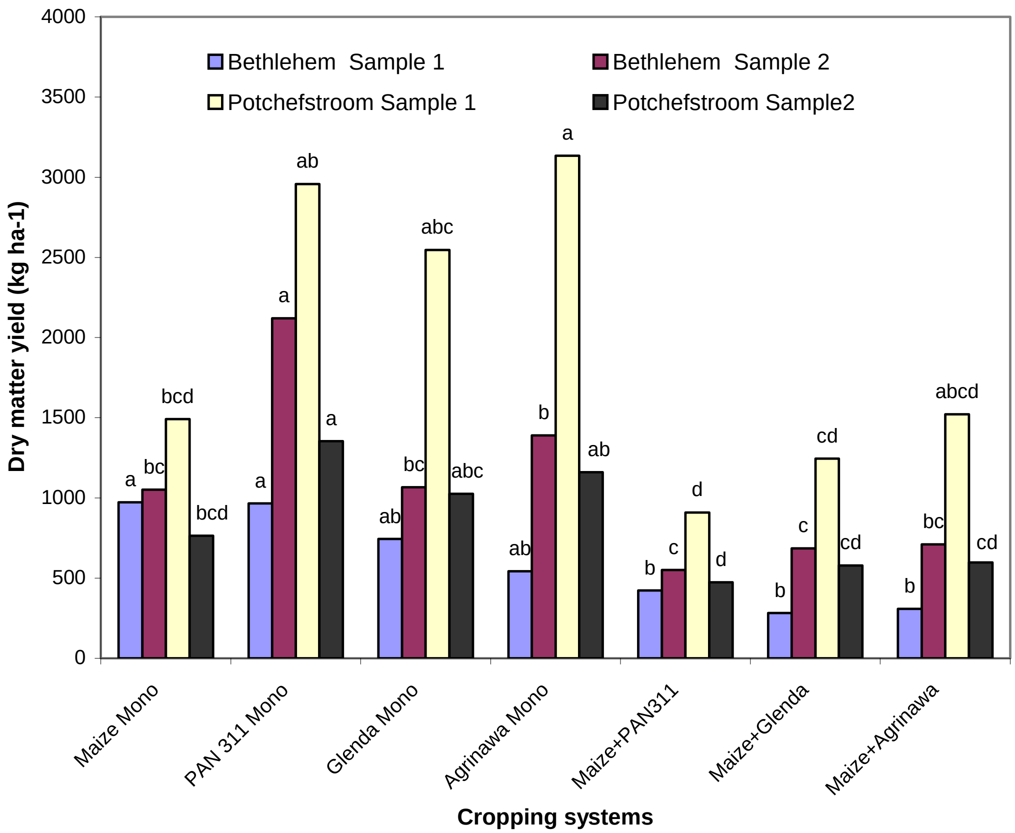

Fig 3.3 Weed dry matter yield (kg ha^{-1}) sampling 1 & 2 at Bethlehem and Potchefstroom during 2006/07 season.

In general for the two seasons at both locations, weeds grew better under sole cropping of the short duration cultivar (PAN311) than with other cultivars (Fig 3.4). This was expected since the same cultivar gave the lowest leaf DMY, which implies that the surface area covered by the cultivar was less, thus allowing better weed growth. Maize intercropping with Agrinawa, especially at Potchefstroom and Agrinawa sole cropping at Bethlehem, gave lowest weed dry matter yields (Fig 3.4). This was also evident because the long duration cultivar, Agrinawa, was able to out yield other cultivars in leaf dry matter yield, thus resulting in better weed control. Maize intercropping with cowpea significantly reduced weed biomass compared to sole cropping, with medium and long duration cowpea cultivars controlling the weeds better than the short duration cultivar.

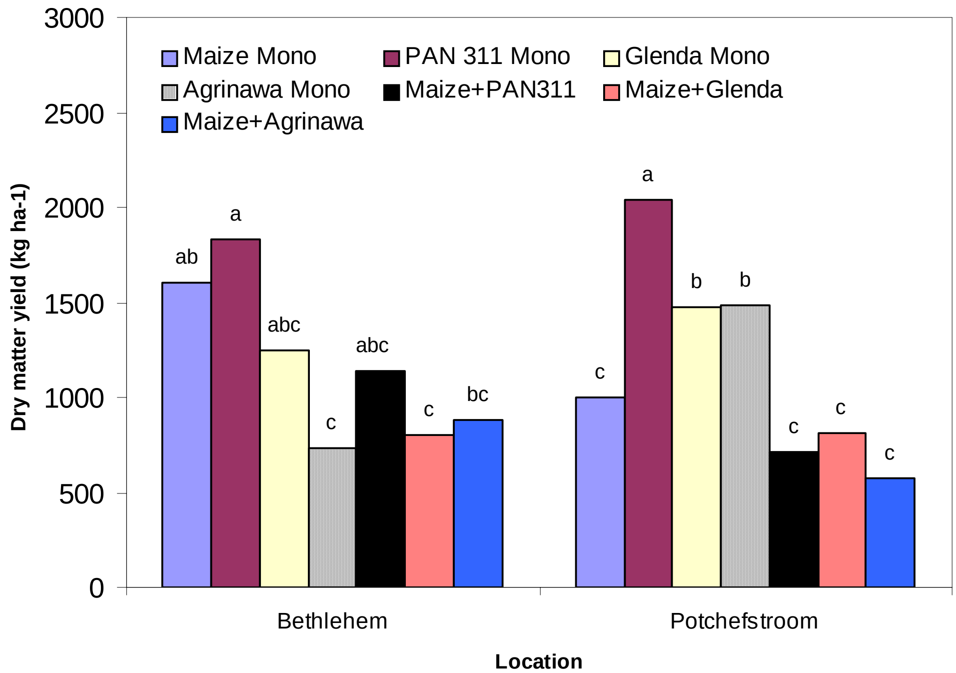

Fig 3.4 Weed dry matter yield (kg ha^{-1}) averages for 2005/06 and 2006/07 seasons at Bethlehem and Potchefstroom.

These results are similar to those of Musambisi, Chivenge & Mariga (2002) who reported that crop rotation and intercropping with field beans (*Pahseolus vulgaris*), groundnuts (*Arachis hypogea* L) and cowpea (*Vigna unguiculata*) reduces the number of weed seeds, especially *Striga* and suppress germination and growth of other weeds. Our results indicated that weed DMY differs with cropping systems, crop growth duration and locality, with Potchefstroom generally having had higher weed biomass compared to Bethlehem. The variation in weed infestation depends on the season and weather conditions, especially soil temperature, moisture and locality (Doggett, 1988). In intercropping, crop-weed competition is determined by the growth habit of the crops and the competing weed species (Callaway, 1992). Erect cowpea cultivars would have a better weed suppression effect than the semi-erect or prostrate cultivars (Wang *et al*., 2004). Important in this regard is the height advantage of long duration cultivars compared to short duration cultivars. Plant growth characteristics such as those of PAN311 (short height) with reduced light interception capabilities, predisposes the crop to weed competition. Higher crop leaf biomass, as was indicated by Callaway & Forcella (1993), increases weed suppression as found in the case of Glenda and Agrinawa. The competitive ability of cowpea improves with taller plants and higher LAI, as was reported by Nangju (1978). Own results correspond with those of Abdin (1996) who found a 10% reduction of weeds with legume intercropping, while Samson (1991) reported a 50% reduction in weed biomass under maize/rye grass intercropping compared to sole cropping. According to Hoffman, Regnier & Carding (1993), hairy vetch (*Vicia villosa*. Roth) reduced weed biomass by 96% without affecting maize yield. Different responses of different legumes to weed infestation were also reported by Vrabel, Minotti & Sweet (1980) when using white and red clover. Shading and better competition for water and nutrients result in better weed control (Altieri & Liebamn, 1988) and this is assumed to have been the case with cowpea cultivars Glenda and Agrinawa. Allelopathic activity of annual legumes that suppresses weed germination and growth of some weed species was reported by White, Worshan & Blum (1989), which could explain the better weed control obtained by medium and long duration cowpea cultivars in the present study.

3.3.5. Summary and conclusions

Different maize growth parameters were affected differently in the two growing seasons at both localities by cropping system and weed infestation. Under the cooler and wetter conditions of Bethlehem, maize monocrop and maize intercropped with a long seasonal cowpea cultivar produced significantly higher LAI compared to other treatments. However, under the warmer and drier conditions of Potchefstroom, LAI was significantly reduced under all the treatments compared to wetter conditions. In areas with higher temperatures and low rainfall, intercropping with diverse seasonal cowpea varieties did not affect maize LAI, whereas at cooler and high rainfall areas, maize LAI was affected by different treatments. At Bethlehem, maize total DMY and 50%-flowering were not affected by different seasonal duration treatments. In general, higher maize total DMY was produced under cooler and high rainfall than under warmer and low rainfall conditions. Maize plant height responded to cropping system under drier conditions at Potchefstroom with maize monocrop and maize intercropped with the medium seasonal cowpea variety having significantly higher plant height compared to all other treatments. At Bethlehem, intercropping and weed infestation significantly reduced number of days to physiological maturity in maize whereas at

Potchefstroom only weed infestation significantly reduced physiological maturity, while different responses were observed for cropping system.

Measured cowpea growth parameters also responded differently to cropping system, weed infestation and their interaction. Medium and long seasonal cowpea cultivars produced significantly more nodules per plant under intercropping conditions and this seemed to be induced by harsher growth conditions, especially at Bethlehem. The opposite was observed under very harsh conditions at Potchefstroom. Despite seasonal variation and location, cowpea nodulation differed with different seasonal growth varieties and cropping systems. Under sole cropping at both locations, leaf and total DMY were decreased with the short seasonal growth cultivar while the long duration cultivar produced the highest DMY. At Potchefstroom under intercropping conditions, leaf DMY of medium and long growth duration cultivars seemed to be enhanced by weed infestation. Generally, weed infestation significantly reduced leaf and total DMY under drier conditions of Potchefstroom than under wet and cooler conditions of Bethlehem. At Bethlehem no weed infestation effect on cowpeas' 50%-flowering was observed while at Potchefstroom weed infestation delayed cowpea date of flowering. All the cowpea treatments duration to 50%-flowering were significantly delayed by intercropping at both locations. This was also the case for physiological maturity especially under the low rainfall of Potchefstroom. Cowpea physiological maturity at Bethlehem was delayed by weed infestation while contrasting results were found at Potchefstroom. This might be an indication that under cooler environments there is less competition for growth resources, especially water, and plants tend to compete less than under drier and warmer conditions. This might be due to the cowpeas' reduced light interception under intercropping conditions compared to sole maize, which is naturally taller than the cowpea and intercept more radiant energy.

Weed DMY differed with cropping systems, cowpea growth duration and locality and there were different weed species at each locality whilst others were common at both localities, e.g., dwarf marigold (*Schkuhria pinnata*) and common pigweed (*Amaranthus hybridus*). Weeds generally grew better and produced more biomass under dry and warmer conditions than under cooler and high rainfall conditions. Weed biomass was better controlled by intercropping maize with medium and long duration cowpea cultivars than with the short duration cultivar. This could be attributed to high leaf and total DMY produced by these former cultivars, which are tall, shaded and competed better with the weeds than the short duration cultivar. Better weed control under intercropping allows for a reduction in herbicide application by farmers as was indicated by Hutchison & McGiffen, (2000), as well as reduced need of land cultivation (Steiner, 1984 and Garrity *et al*., 1992) and improved yield stability on weedy fields (Linquist & Mortensen, 1998).

From the experiment it can be concluded that intercropping does not affect maize total DMY but affects maize LAI, plant height and physiological maturity at both locations. Intercropping affected all cowpea growth parameters with the medium and long duration cultivars producing more nodules per plant, especially when intercropped under cooler and wetter conditions. Agrinawa produces the highest leaf and total DMY and is more tolerant to weed infestation than other cultivars under the same conditions. Intercropping treatments significantly reduced weed DMY and more DMY is produced under warmer and drier conditions. The long duration cultivar had more significant effect on weed dry matter reduction.

Maize as sole or intercrop with Agrinawa at Bethlehem can be recommended for better LAI. Maize grown as sole and intercrop at Bethlehem can also be recommended for high total DM yield. At Potchefstroom, maize sole or intercropped with Glenda can be recommended for increased plant height. Intercropping with Glenda and Agrinawa at Bethlehem can be recommended for better nodulation. Agrinawa monocrop can be recommended for high leaf and total DMY at Potchefstroom especially under zero weeds. Agrinawa intercropping at Potchefstroom and Agrinawa sole crop at Bethlehem can be recommended for better weed control.

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CHAPTER 4: EFFECTS OF INTERCROPPING ON GRAIN YIELD AND YIELD COMPONENTS OF MAIZE AND COWPEA AND N_2 YIELD AS AFFECTED BY WEED INFESTATION

4.1. Introduction

Maize-cowpea intercropping is a very common practice in the tropics with its productivity depending upon the complementary effect between the companion crops (Vesterager, Nielsen & Hogh-Jensen, 2008). Productivity enhancement between maize and legume intercrops requires improving the interspecies relationship and reducing competition effects (Rezende & Ramalho, 1994). This could probably be achieved by planting compatible cultivars with minimum intercropping competition and maximum complementary effects (Rao & Mittra, 1990). One of the most important agronomic factors determining whether an intercrop system will be advantageous or not with regard to grain yield is their spatial arrangement (Natarajan & Shumba, 1990). Rao & Mittra (1990) indicated that different bean cultivars have different growth habits and duration, which may result in different responses to maize intercropping. Thus, an ideal legume is the one with high grain yield, which reduces competitive effect on the companion cereal crop (Mutangamiri, Mariga & Chivenge, 2001).

Intercropping is normally practiced under limited soil fertility and low input conditions in the tropics. Among the most important advantages include high overall yield, higher use efficiency of natural resources and improved yield stability (Fukai & Trenbath, 1993) and efficient use of labor and land (Baldy & Stigter, 1997). Cereal/legume intercropping could benefit small-holder farming systems by generating sustainable income, minimizing the risks of crop failure and providing balanced diet with sources of starch and proteins (Chemeda, 1997). The variation in yields for both legumes and cereals are mainly associated with poor agronomic practices and cropping systems (Ofori & Stern, 1986 and Trinah & Wahua, 1985). According to Ayisi, Nkgapele & Dakora (2000), maize and cowpea are the major food crops grown by small-scale farmers in Africa including South Africa. Henriet *et al.* (1997) and van Ek *et al.* (1997) reported that most African farmers prefer a traditional system of randomly planting without any defined rows or planting legumes on intra-rows or planting the two crops on the same hole (Fawusi, Wanki & Nangju, 1982). These practices result in lower planting density, which in turn resulted in lower grain yield (Ndakidemi & Dakora, 2007). The variability of component crops over space and time in both traditional and conventional cropping systems are used to enhance productivity and its sustainability. This is mainly manipulated to enhance complementary effect and to reduce competition in order to maximize agronomic and physiological advantages (Ofori & Stern, 1986; Silwana & Lucas, 2002). Different responses have been reported on maize yield as affected by intercropping. Shumba, Dhiwayo & Mukoko (1990) and Siame, Willey & Morse (1998) reported depression of maize yield when intercropped with cowpeas, while Mpangane *et al*. (2004), Patra *et al*. (1986) and Singh, Tripati & Negi (1974) reported a maize yield increase due to intercropping. Therefore, there is a need to critically investigate the response of component crops in each locality, which will be beneficial to the farmers in that area (Mpangane *et al*., 2004).

According to Tsubo *et al*. (2003), most African farmers practice small farming systems. Their farming plays a key role for food production hence the majority experiences food security problems (Van Rooyen & Sigwele, 1998). Throughout southern Africa, yield reduction is increased by adverse weather conditions and droughts. Under rainfed cropping systems, this results in high yield variation. Besides the two thirds of cultivated land in eastern and southern Africa that is occupied by maize, productivity of small-scale farmers is still low (Blackie & Jones, 1993 and Myaka *et al*., 2006). In areas with marginal rainfall, poor soil fertility and limited use of fertilizer, most resource poor farmers depend on cowpea because of its ability to fit into diverse cropping systems (Summerfield & Minchin, 1983). Despite its importance, very limited information is available on the yield and N_2-fixation of different growth duration cowpea cultivars under low soil fertility and intercropping conditions. Conflicting reports exist on whether the cereal crop benefits from the N fixed by the legume crop in an intercropping system. Willey (1979) estimated the N contribution from legume to cereal at 40 kg N ha^{-1} while Searle *et al*. (1981) did not find any evidence of such a benefit. Quantitative and comparative data on N_2-fixation and N beneficial effect of the companion crop in an intercropping system is scarce (Senaratne, Liyanage & Soper, 1995). In maize/cowpea intercropping, maize derived 25-45 mg N $plant^{-1}$, which varied between 11-20%. In comparisons between cowpea, groundnut and mungbean, it was found that more N_2-fixation was observed with intercropped groundnut contributing 552 mg N plant^{-1} followed by intercropped mungbean and cowpea with 161 and 197 mg N plant^{-1}, respectively. Nitrogen transfer from grain legume to an associated companion cereal component was reported (Elmore & Jackobs, 1986) and also from forage legumes to grasses (Simpson, 1976). During intercropping, the legume may increase the supply of available N in the root medium but also compete for N with cereals. In some instances, competition by the legumes for N is high and results in reduced N uptake by the cereal (Simpson, 1965).

Weed infestation is one of the major constraints to crop production in the tropics regardless of the cropping system (Parker and Fayer, 1975 and Okigbo, 1978). Their role in crop mixtures as opposed to sole crops is important to both small and large-scale farmers in making decisions (Ayeni, Duke & Akobundu, 1984). Maize and cowpea normally suffer approximately 40 and 53% reduction respectively when exposed to full season weed interference (Akobundu, 1979). When intercropped species are in direct competition for the same growth-limiting factor, an increase in yield in one component crop could result in a decrease in yield of another crop. Competition from weeds can be lessened by growing two or more crop species in the same area of land (Altieri & Liebman, 1986). In maize and cowpea intercropping, Ayeni *et al*. (1984) mentioned the importance of controlling weeds initially to develop a canopy sufficient for weed suppression. From unweeded and unfertilised maize plots, weeds removed 45 kg N ha^{-1} (Sawhney, Moolani & Gill, 1977). Weeds removes 64-83% of the total nutrients available to maize (Lambert & Arnason, 1980).

Land equivalent ratio (LER), which is the amount of sole cropped land required to produce the same yield as one unit of intercropped land, is reported to be favored by low N fertility, limited moisture and weed competition (Weil & McFadden, 1991) and decreased by increasing N rates (Rao & Willey, 1980). The combination of cereal-legume intercropping on average usually results in better yields than monocrops based on the concept of LER (Ndakidemi & Dakora, 2007). This is because of more efficient use of land by growing more crops on the same piece of land than growing one crop at a time.

The aim of this study was to investigate the effects of intercropping different cowpea cultivars on maize and cowpea grain yield, yield parameters and N_2 yield.

4.2. Materials and methods

The materials and methods for this chapter are same as those presented in Chapter 2.

4.3. Results and discussion

4.3.1. Effect of cropping system on maize grain yield and yield components

4.3.1.1. Maize ear number per plant

During the 2005/06 season at Bethlehem, no significant differences were observed (Table 1- Appendix B) and the mean ear number per plant was 1.8292. During the 2006/07 season, maize monocrop (1.4033) and maize intercropped with PAN311 and Glenda (1.4817 and 1.2567) had the highest number of ears per plant while maize intercropped with Agrinawa had the lowest with 1.0117 (Table 4.1). Although no significant weed effects were observed during both seasons, weed infestation on average reduced number of ears per plant by 16.5%. There was a 29.6% decrease in number of ears per plant in the second season, indicating the significance of seasonal variation (Table 4.1). This was as a result of lower rainfall in the second season (Fig 2.1), which could have triggered competition for water and nutrients component crops and reduced plant ear development (Muoneke *et al*., 2007). At this location (Bethlehem), especially during the second season, it was clear that intercropping with long-season cowpea cultivars significantly reduced maize ear number per plant.

Table 4.1 The effects of maize cropping system and weed infestation on maize ear number per plant during 2005/06 and 2006/07 seasons at Bethlehem.

Cropping system	Weeds	Zero Weeds	Mean
2006/07 Growing season			
Maize Mono	1.2100abc	1.5967a	1.4033a
Maize + PAN311	1.4100ab	1.5533a	1.4817a
Maize + Glenda	1.0967bc	1.4167ab	1.2567ab
Maize + Agrinawa	1.0400bc	0.9833c	1.0117b
Mean	1.1892a	1.3875a	1.2884
Two seasons' average			
Maize Mono	1.4700ab	1.9467a	1.7083a
Maize + PAN311	1.4567b	1.6600ab	1.5583ab
Maize + Glenda	1.4300b	1.6400ab	1.5350ab
Maize + Agrinawa	1.3200b	1.5400ab	1.4300b
Mean	1.4192b	1.6967a	

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

No significant differences were observed in cropping system at Potchesftroom (Table 1- Appendix B) and the mean ear number per plant were 1.8833 and 0.7104 during the 2005/06 and 2006/07 seasons, respectively, which resulted in a 62.3% reduction in ear number per plant in the second season compared to the first season. It can be concluded that intercropping with a long seasonal cowpea cultivar under cooler and wetter conditions significantly reduces maize ear number per plant.

4.3.1.2. Maize ear length

At Bethlehem during both seasons no significant differences were observed (Table 1- Appendix B) although there was a 19.5% reduction in maize ear length in the second season compared to the first season with means of 18.575 and 14.961 for the 2005/06 and 2006/07 seasons, respectively.

At Potchefstroom during the 2005/06 season, no significant differences were observed (Table 1- Appendix B) and the mean ear length was 17.296 cm. During the 2006/07 season, weed infestation reduced ear length from 15.369 cm under no weed infestation to 13.739 cm under weed infestation (Table 4.2). When crops compete for available nutrients especially under intercropping and in the presence of the weeds, grain yield will be reduced (Muoneke *et al*., 2007). Sole maize under no weed infestation was the highest (17.083 cm) and maize intercropped with Agrinawa had the lowest (11.990 cm) under weed infestation. Similar results were also observed on average for the two seasons between the weed treatments. This was an indication that weed infestation and intercropping, especially with the long seasonal cultivar, significantly reduces ear length under drier and warmer environments. This might be attributed to more competitive effect of long seasonal cowpea cultivar compared to other cultivars. This, however, differs from the results of Thwala & Ossom (2004) who did not find any difference on maize sole crop and intercropping with sugar bean and groundnut.

Table 4.2 The effects of maize cropping system and weed infestation on maize ear length during 2005/06 and 2006/07 seasons at Potchefstroom.

Cropping system	Weeds	Zero Weeds	Mean
2006/07 Growing season			
Maize Mono	13.767bc	17.083a	15.425a
Maize + PAN311	14.767abc	15.200abc	14.983a
Maize + Glenda	14.433abc	14.000abc	14.217a
Maize + Agrinawa	11.990c	15.300ab	13.645a
Mean	13.739b	15.369a	
Two seasons' averages			
Maize Mono	15.017bc	17.483a	16.430a
Maize + PAN311	16.317abc	16.133abc	16.225a
Maize + Glenda	15.900abc	15.467abc	15.683a
Maize + Agrinawa	13.997c	16.783ab	15.390a
Mean	15.308b	16.557a	

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

4.3.1.3. Maize seeds per ear

Non-significant differences were observed during the two seasons at both locations (Table 1- Appendix B) and there was a 42.1 and 62.3% reduction in maize seeds per ear during 2006/07 season compared to 2005/06 season at Bethlehem and Potchefstroom, respectively. The means were 595.02 and 344.37 at Bethlehem and 515.71 and 194.67 at Potchefstroom during the 2005/06 and 2006/07 seasons, respectively.

4.3.1.4. Maize 100 seed mass

At Bethlehem during both seasons, 100 seed mass was significantly affected by weed infestation (Table 1- Appendix B). Weed infestation reduced 100 seed mass by 5.8 and 10.7% during the 2005/06 and 2006/07 growing seasons, respectively, and this resulted in 8.2% average mass reduction by weed infestation (Table 4.3). This was influenced by competition effect on environmental resources especially water and nutrients which reduced maize yield (Gomes *et al*., 2007). During the 2005/06 season, the highest mass was recorded with maize monocrop (34.997 g) and maize intercropped with PAN311 (35.097 g), in the absence of weeds while maize intercropped with Agrinawa gave the lowest (31.830 g) in the presence of weeds. During the 2006/07 season, maize intercropped with Agrinawa in the absence of weeds gave the highest mass (32.967 g) while maize monocrop and maize intercropped with Agrinawa gave the lowest (27.733 g) under weed infestation. At

Bethlehem, it seemed that under higher rainfall maize monocrop and intercropping with a short duration cultivar significantly promoted seed mass. This might be attributed to less competition under sole and intercropping with short duration cultivars, which flowered and matured early. On average for the two seasons, it can be concluded that maize intercropped with Agrinawa in the absence or presence of weeds gave the highest and lowest 100 seed mass, respectively (Table 4.3). A non-significant difference in 100 seed mass between sole and intercropped maize was also reported by Francis *et al*. (1978) and Thwala & Ossom (2004).

At Potchefstroom during both seasons, the affect of cropping system was not significant (Table 1- Appendix B) and on average there was a 27% mass reduction during 2006/07 compared to the 2005/06 season. The means were 38.204 and 29.296 g for the 2005/06 and 2006/07 seasons, respectively. This was an indication of severe environmental conditions having impacted on seed mass, especially during the 2006/07 growing season. There is a high variation under rainfed conditions, which results from adverse weather conditions (Table 2.3 and Fig 2.2).

Table 4.3 The effects of maize cropping system and weed infestation on maize 100 seed mass (g) during 2005/06 and 2006/07 seasons at Bethlehem.

Cropping system	Weeds	Zero Weeds	Mean
	2005/06 Growing season		
Maize Mono	32.493ab	34.997a	29.417a
Maize + PAN311	32.727ab	35.097a	31.217a
Maize + Glenda	32.373ab	32.577ab	29.583a
Maize + Agrinawa	31.830b	34.850ab	30.350a
Mean	32.356b	34.380a	
	2006/07 Growing season		
Maize Mono	27.733c	31.100ab	31.582a
Maize + PAN311	29.833abc	32.600a	32.567a
Maize + Glenda	28.467bc	30.700abc	31.032a
Maize + Agrinawa	27.733bc	32.967a	31.847a
Mean	28.442b	31.842a	
	Two seasons' averages		
Maize Mono	30.113bc	33.050ab	31.582a
Maize + PAN311	31.283abc	33.850a	32.567a
Maize + Glenda	30.423bc	31.640abc	31.032a
Maize + Agrinawa	29.783c	33.910a	31.847a
Mean	30.401b	33.112a	

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

4.3.1.4. Maize ear mass

Maize ear mass at Bethlehem was affected by cropping system and weed infestation during the 2005/06 and 2006/07 season, respectively (Table 1- Appendix B). During the 2005/06 season, maize monocrop produced significantly higher ear mass (5 522.1 kg ha^{-1}) compared to all the intercrop treatments, indicating the relative competitive effect of intercrops compared to sole cropping (Table 4.4). Due to drier conditions in the 2006/07 season, which could have triggered competition, weed infestation reduced ear mass by 40.2% compared to zero weed treatments. Similarly to the first season, maize monocrop in the absence of weeds produced the highest ear yield (5 248.3 kg ha^{-1}) while maize intercropped with Agrinawa in the presence of weeds produced the lowest (1 875.9 kg ha^{-1}). At this locality, maize ear yield was significantly reduced by cowpea intercropping during both seasons except in the case of maize intercropped with PAN311 (4 111.3 kg ha^{-1}) during the 2006/07 season, which was higher than all the main treatments during that season. PAN311 as a short duration cultivar was probably less competitive for growth resources than the medium and long duration cowpea cultivars. All the treatments performed better during the first season compared to the second season, thus the weed effect was more severe during the second season for mentioned earlier.

Maize ear mass at Potchefstroom was affected by cropping system and weed infestation during the 2005/06 season, but by only the cropping system during the 2006/07 season (Table 1- Appendix B). During the 2005/06 season, maize monocrop treatment produced the highest ear yield (5 489.8 kg ha^{-1}) and this was higher than all the intercrop treatments but not significantly different to maize intercropped with Agrinawa (Table 4.11). Maize monocrop in the absence of weeds produced significantly higher ear yield (5 911.6 kg ha^{-1}) while maize intercropped with Glenda (3 802.9 kg ha^{-1}) produced the lowest in the presence of weeds. During this season, weed infestation reduced ear yield by 9.8% compared to no weed infestation. During the 2006/07 season, maize monocrop treatment again produced significantly higher ear yield (3 076.0 kg ha^{-1}), which was 44.1% lower than the previous season. Between the two seasons at Bethlehem and Potchefstroom, there was a 29.1 and 59.5% reduction in ear mass in the second season compared to the first season, respectively. This is an indication that severe weather conditions coupled by intercropping and weed infestation caused a significant reduction in maize ear mass.

Table 4.4 The effects of maize cropping system and weed infestation on maize ear mass (kg ha^{-1}) for the 2005/06 and 2006/07 seasons at Bethlehem and Potchefstroom.

Cropping system	Weeds	Zero Weeds	Mean
Bethlehem	Maize ear mass (kg ha^{-1})		
	2005/06 Growing season		
Maize Mono	5089.9ab	5954.4a	5522.1a
Maize + PAN311	4591.5ab	4878.5ab	4735.0b
Maize + Glenda	3808.0b	4854.3ab	4331.1b
Maize + Agrinawa	3736.4b	4780.4ab	4258.4b
Mean	4306.5a	5116.9a	4711.7
	2006/07 Growing season		
Maize Mono	2188.8cd	5248.3a	3718.5ab
Maize + PAN311	3549.6abcd	4673.0ab	4111.3a
Maize + Glenda	2378.6cd	3782.9abc	3080.8ab
Maize + Agrinawa	1875.9d	3018.8bcd	2447.3b
Mean	2498.2b	4180.8a	3339.5
	Two seasons' averages		
Maize Mono	3639.3bcd	5601.3a	4620.3a
Maize + PAN311	4070.6bc	4775.8ab	4423.2ab
Maize + Glenda	3093.3cd	4318.6b	3705.9bc
Maize + Agrinawa	2806.2d	3899.6bcd	3352.9c
Mean	3402.3b	4648.8a	
Potchefstroom			
	2005/06 Growing season		
Maize Mono	5068.0ab	5911.6a	5489.8a
Maize + PAN311	4214.0bc	4364.5bc	4289.2b
Maize + Glenda	3802.9c	4448.2bc	4125.6b
Maize + Agrinawa	4725.2bc	5017.9ab	4871.6ab
Mean	4452.5b	4935.6a	4694.1
	2006/07 Growing season		
Maize Mono	3466.2a	2685.8b	3076.0a
Maize + PAN311	1714.7c	1363.3cd	1539.0bc
Maize + Glenda	1997.5bc	1865.8bc	1931.6b
Maize + Agrinawa	647.7d	1453.5c	1050.6c
Mean	1956.5a	1842.1a	1899.3
	Two season's averages		
Maize Mono	4267.1a	4298.7a	4282.9a
Maize + PAN311	2964.3bc	2863.9bc	2914.1b
Maize + Glenda	2900.2bc	3157.0bc	3028.6b
Maize + Agrinawa	2686.4c	3235.7b	2961.1b
Mean	3204.5a	3388.8a	

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

On average for the two seasons at each locality, it is evident that ear mass was mainly affected by cropping system effect and weed infestation, and weed infestation reduced ear mass compared to no weed infestation. Maize monocrop in the absence of weeds produced the highest ear yield while maize intercropped with Agrinawa in the presence of weeds produced the lowest yield at both locations (Table 4.4). This is an indication that both intercropping and weed infestation significantly reduces ear yield compared to no weed and sole treatments and that the longer growth duration of the legume intercrop exacerbated the negative effect. This differs from the findings of Thwala & Ossom (2004) who did not find any significant difference between maize sole crop and intercropping with sugar bean and groundnut on ear mass.

4.3.1.5. Maize grain yield

Similar to ear mass at Bethlehem, maize grain yield was significantly affected by cropping system and weed infestation during the 2005/06 and 2006/07 seasons (Table 1- Appendix B). During the 2005/06 season, maize monocrop produced significantly higher grain yield (4 615.0 kg ha^{-1}) than all the intercrop treatments except for maize intercropped with PAN311 with 4 044.6 kg ha^{-1} (Table 4.5). During the 2006/07 season, weed infestation resulted in a 41.7% reduction of maize grain yield. Maize monocrop in the absence of weeds produced significantly higher yield (4 136.4 kg ha^{-1}) while maize intercropped with Agrinawa in the presence of weeds produced the lowest yield (1 411 kg ha^{-1}). Agrinawa as a long duration cultivar competed strongly with maize for the growth resources and this was worsened by the presence of weeds. This was a clear indication of the significant detrimental effects of intercropping and weed infestation on maize grain yield under limited rainfall conditions.

Maize grain yield at Potchefstroom was significantly affected by cropping system and weed infestation during the 2005/06 season, and by only the weed infestation treatment during the 2006/07 season (Table 1- Appendix B). The warmer and drier conditions of Potchefstroom were severely affected by the presence of weeds especially during the 2006/07 season. During both the 2005/06 and 2006/07 seasons, maize monocrop produced significantly higher yield (4 545.6 and 2 301.9 kg ha^{-1}, respectively), while all the intercrop treatments produced the lowest yields (Table 4.6). During the 2005/06 season, weed infestation reduced maize grain yield by 10.8% compared to zero weed infestation. In addition to intercropping, one of the factors that reduces maize grain yield is dry conditions that occur especially during the flowering period (Amede, 1995). This was the case during the 2006/07 season, especially at Potchefstroom.

Table 4.5 The effects of maize cropping system and weed infestation on maize grain yield (kg ha^{-1}) for the 2005/06 and 2006/07 seasons at Bethlehem and Potchefstroom.

Cropping system	Weeds	Zero Weeds	Mean
Bethlehem	Maize grain yield (kg ha^{-1})		
	2005/06 Growing season		
Maize Mono	4309.6ab	4920.3a	4615.0a
Maize + PAN311	3993.6ab	4095.7ab	4044.6ab
Maize + Glenda	3258.4b	4238.6ab	3748.5b
Maize + Agrinawa	3214.2b	4062.1ab	3638.2b
Mean	3694.0a	4329.2a	
	2006/07 Growing season		
Maize Mono	1760.9cd	4136.4a	2948.7ab
Maize + PAN311	2715.5abcd	3697.4ab	3206.4a
Maize + Glenda	1847.2cd	3031.9abc	2439.6ab
Maize + Agrinawa	1411.5d	2406.8bcd	1909.2b
Mean	1933.8b	3318.1a	
	Two seasons' averages		
Maize Mono	3035.3bcd	4528.4a	3781.8a
Maize + PAN311	3354.6bc	3896.5ab	3625.5a
Maize + Glenda	2552.8cd	3635.3ab	3094.0ab
Maize + Agrinawa	2312.9d	3234.5bcd	2773.7b
Mean	2813.9b	3823.7a	
Potchefstroom			
	2005/06 Growing season		
Maize Mono	4181.4ab	4909.9a	4545.6a
Maize + PAN311	3454.4bc	3597.0bc	3525.7b
Maize + Glenda	3135.4bc	3768.6bc	3452.0b
Maize + Agrinawa	3883.9bc	4163.3ab	4023.6ab
Mean	3663.8b	4109.7a	
	2006/07 Growing season		
Maize Mono	2520.5a	2083.3ab	2301.9a
Maize + PAN311	1191.7cd	934.2cd	1062.9b
Maize + Glenda	1256.0c	1398.4bc	1327.2b
Maize + Agrinawa	404.0d	1007.4cd	705.7b
Mean	1343.0a	1355.8a	
	Two season's averages		
Maize Mono	3350.9a	3496.6a	3423.8a
Maize + PAN311	2323.0bc	2265.6bc	2294.3b
Maize + Glenda	2195.7bc	2583.5bc	2389.6b
Maize + Agrinawa	2143.9c	2585.4b	2364.7b
Mean	2503.4b	2732.8a	

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

Reduced maize yield under intercropping and weed infestation was also reported by Silwana & Lucas (2002). Opposite results were found by Olufemi, Pitan & Odebiyi (2001), Mpairwe *et al.* (2002) and Dapaah *et al*. (2003) with high cereal grain yield under intercropping being reported. According to Nzabi *et al*. (2000), maize grain yield differs with different legume species and intercropping produces higher maize grain yield than sole cropping.

On average for the two seasons at each locality, similar as for ear mass, cropping system and weed infestation effect significantly affected maize grain yield. Maize monocrop, especially in the absence of weeds, produced the highest yield at each locality compared to all the intercrop treatments, while maize intercropped with Glenda and Agrinawa produced the lowest (Table 4.5). Natarajan & Willey (1986) suggested more total populations under intercrops compared to sole cropping under stress conditions might results in less intercrop yields than sole crop yields because of increased competition for moisture. On crop growth, Silwana & Lucas (2002) also reported taller plants under sole cropping compared to intercropping both in the absence and presence of weeds. Higher grain yield by sole maize compared to intercrops with kenaf and the combination of kenaf and African yam bean (AYB) was also found by Adeniyan *et al*. (2007). Weed infestation resulted in 26.4 and 8.4% grain yield reduction at Bethlehem and Potchefstroom, respectively. This could have probably been influenced by weed species variation and density between the two localities, which might have resulted in different responses on maize. Bethlehem has a light texture soil, which has low moisture holding capacity (Macvicar *et al*., 1977), which results in reduced yields especially under intercropping (Natarajan & Willey (1986).

Yield reduction under intercropping could be associated with the competition effect by the component crops for nutrients, moisture and space (Enyi, 1973; Okpara & Omaliko, 1995 and Adeniyan *et al*., 2007). The reduction of maize yield during the 2006/07 season compared to 2005/06 season also had similar response to maize LAI, total DMY and plant height. Maize intercropping especially with Agrinawa at Bethlehem, reduced maize grain yield by 29.5% while maize intercropped with PAN311 at Potchefstroom reduced maize grain yield by 33.9% (Table 4.6). Similar results were also found by Chemeda (1997) with maize-bean intercropping and

Thwala & Ossom (2004) with maize-sugar bean and maize groundnut intercropping. According to Parker & Fayer (1975) and Okigbo (1978), weed infestation is one of the major constraints to crop production in the tropics regardless of the cropping system. Because of improved maize yield under intercropping, Nzabi *et al*. (2000) concluded that maize benefits from legume intercropping especially in the case of soybean, groundnuts and yellowgrams. The reduction in number of days to physiological maturity results in low metabolic processes and reduces time to harvest and yield (Afuakwa & Crookston, 1984). It can be concluded that maize performs better under sole cropping conditions in the absence of weeds especially under cooler and wetter conditions of Bethlehem.

4.3.2. Effect of cropping system on cowpea grain yield and yield components

4.3.2.1. Cowpea pod number per plant

At Bethlehem, significant effects were observed for the cropping system during the 2005/06 season and for weed infestation during the 2006/07 season (Table 3-Appendix B). During the 2005/06 season, Glenda and Agrinawa monocrop treatments had the highest number of pods per plant (42 and 39 pods per plant, respectively) (Table 4.6). Intercropping significantly reduced the number of pods per plant of all the treatments except in the case of PAN311. As mentioned in chapter 3, the short duration cultivar, PAN311, managed to flower and mature early to sustain drought and shading unlike Glenda and Agrinawa, which grew longer (Hall, 2004). During the 2006/07 season, weed infestation reduced cowpea number of pods per plant by 23.7% compared to no weed infestation. The highest number of pods per plant was observed with Agrinawa monocrop (15) under no weed infestation while PAN311 and Agrinawa mono under weed infestation had the lowest (6). There was a 64.8% reduction in number of pods per plant in the second season compared to the first season. This is because the 2005/06 season experienced lesser rainfall than the long term averages which could have resulted in more competition for growth resources, especially water (Fig 2.1). Agrinawa and PAN311 monocrop were the two treatments that significantly contributed to a reduction in number of pods per plant compared to all the other treatments.

At Potchefstroom during the 2005/06 season, effects for cropping system, weed infestation and their interaction were significant, while in the 2006/07 season only the effects for cropping system and weed infestation were significant (Table 3- Appendix B). During the 2005/06 season, similar to Bethlehem, weed infestation reduced the number of pods per plant by 24.9% compared to no weed infestation (Table 4.6). This can also be related to more competition and shading under intercropping conditions compared to sole cropping. PAN311 monocrop produced the most pods per plant (49) under no weed infestation while Agrinawa intercropped with maize produced the lowest (2) under weed infestation. Glenda and PAN311 monocrops were the two treatments that contributed significantly to reduced pods per plant under weed infestation. As motioned in chapter 3, PAN311 and Glenda and produced the least leaf and total dry matter yield. They were therefore unable to shade the weeds as more weed DM produced and thereby resulting in more competition. During the 2006/07 season, Glenda and PAN311 sole crops produced the highest number of pods per plant (17 and 19, respectively) while Glenda intercrop produced the lowest (2) number of pods per plant. In the 2006/07 season, weed infestation resulted in 30% reduction in number of pods per plant. Between the two seasons for cropping system, there was a 44.1% reduction in number of pods per plant in the second season compared to the first season. Generally, the 2006/07 season experienced lesser rainfall than the long-term averages, which could have resulted in more competition for growth resources between the crops (Fig 2.2). Ndakidemi & Dakora (2007) reported a reduction in cowpea number of pods per plant under intercropping compared to sole cropping.

The average effect for the two seasons at Bethlehem indicated that the medium and long duration cultivars (Glenda and Agrinawa) as monocrops had significantly higher number of pods per plant (26 and 25, respectively). The short duration cultivar, PAN311 as monocrop and intercrop had the lowest with 15 and 12 pods per plant, respectively. The medium and long duration cultivars (Glenda and Agrinawa) are probably well adapted to the cooler and wetter conditions of Bethlehem as the also produced more leaf and total DMY yield. At Potchefstroom, PAN311 sole crop seemed well adapted to conditions by producing the highest number of pods per plant (31). Glenda and Agrinawa intercrops produced the lowest with 5 pods per plant each. At Potchefstroom, weed infestation reduced the number of pods per plant by 27.9% compared to no weed infestation. Chemeda (1997) did not find any difference in bean pod number per plant between sole and intercropping treatments while different genotypes differed significantly with regard to number of pods per plant.

Table 4.6 The effect of cowpea cropping system and weed infestation on cowpea pod number per plant for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Pod number per plant		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	18.000de	26.000cde	22.000c
Glenda Mono	36.667abc	47.333a	42.000a
Agrinawa Mono	33.667abcd	46.000ab	39.833a
PAN311+Maize	24.667cde	12.333e	18.500c
Glenda+Maize	27.333cde	22.333cde	24.833c
Agrinawa+Maize	34.000abcd	30.667bcd	32.333b
Mean	29.056a	30.778a	29.917
	2006/07 Growing season		
PAN311 Mono	6.000de	13.667ab	9.833ab
Glenda Mono	10.333abcde	10.667abcde	10.500ab
Agrinawa Mono	6.667cde	15.333a	11.000ab
PAN311+Maize	8.000bcde	5.667e	6.833b
Glenda+Maize	11.000abcde	14.333a	12.667a
Agrinawa+Maize	12.667abc	12.000abcd	12.333a
Mean	9.111b	11.944a	10.527
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	43.333b	49.333a	46.333a
Glenda Mono	21.000c	36.000b	28.500b
Agrinawa Mono	11.667def	14.667cd	13.167c
PAN311+Maize	12.667cde	14.667cd	13.667c
Glenda+Maize	4.667efg	8.667defg	6.667cd
Agrinawa+Maize	2.333g	4.000fg	3.167d
Mean	15.944b	21.222a	18.583
	2006/07 Growing season		
PAN311 Mono	13.667bc	25.000a	19.333a
Glenda Mono	17.667b	16.333b	17.000
Agrinawa Mono	5.667de	9.000cde	7.333b
PAN311+Maize	8.667cde	8.333cde	8.500b
Glenda+ Maize	2.333e	3.000e	2.667c
Agrinawa+Maize	3.333de	11.667bcd	7.500b
Mean	8.556b	12.222a	10.389

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

4.3.2.2. Cowpea pod length

At Bethlehem, significant differences were observed in cropping systems during the 2005/06 season while no differences were significant for the 2006/07 season (Table 3-Appendix B). Mean pod length was 15.05 cm. During the 2005/06 season, PAN311 and Glenda monocrop had the longest pod lengths (15.10 and 13.70 cm) and this was significantly reduced under intercropping (Table 4.7). This could also be associated with the shading and competition effects under intercropping conditions. Glenda intercrop had the shortest pod length (10.36 cm) and in general, there was a significant reduction of pod length under intercropping compared to sole cropping. At this location there was a 21% increase in pod length during the second season compared to the first season. This is because cowpea is a drought tolerant crop and can perform better under harsher conditions like during the 2006/07 season.

At Potchefstroom during the 2005/06 season, significant differences were observed in cropping system while in 2006/07 season the effects for cropping system and the interaction with weeds were significant (Table 3- Appendix B). During the 2005/06 season at Potchefstroom, PAN311 mono and intercrop had significantly longer pod lengths (15.71 and 14.41 cm) compared to other treatments (Table 4.7). Similar results were also observed during the 2006/07 season. The short duration cultivar (PAN311) seemed to well adapted to warmer and drier conditions of Potchefstroom. Agrinawa intercrop produced the shortest pod length (2.66 cm) and there was a significant reduction in pod length under intercropping conditions. The shortest pod length (9.73 cm) was observed with Glenda intercrop and there was a 35.7% increase in pod length in the second season compared to the first season. On average for the two locations, only the cropping system effect was significant and the short duration cultivar, PAN311 produced the longest pod length while Glenda and Agrinawa intercrops generally had the shortest pod lengths. In all the treatments, cowpea pod length seemed to decrease with increasing growth duration. The more biomass produced means that the crop converted the PAR energy into vegetative production rather than reproduction. This was also observed with high leaf and total DMY by the medium and long duration cultivars in chapter 3.

Table 4.7 The effect of cowpea cropping system and weed infestation on cowpea pod length for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Pod length (cm)		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	14.800ab	15.400a	15.100a
Glenda Mono	14.133abc	13.267abcd	13.700ab
Agrinawa Mono	11.167def	11.933cdef	11.550cd
PAN311+Maize	12.000cde	10.567ef	11.283cd
Glenda+Maize	11.433def	9.300f	10.367d
Agrinawa+Maize	12.733bcde	12.667bcde	12.700bc
Mean	12.711a	12.189a	12.45
	2006/07 Growing season		
PAN311 Mono	16.233a	15.367ab	15.800a
Glenda Mono	14.267ab	13.767b	14.017b
Agrinawa Mono	14.567ab	14.433ab	14.500ab
PAN311+Maize	15.967a	15.967a	15.967a
Glenda+Maize	14.400ab	14.433ab	14.417ab
Agrinawa+Maize	15.300ab	15.900a	15.600a
Mean	15.122a	14.978a	15.05
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	14.867ab	16.567a	15.717a
Glenda Mono	13.933ab	12.100b	13.017b
Agrinawa Mono	6.700c	8.133c	7.417c
PAN311+Maize	14.267ab	14.567ab	14.417ab
Glenda+Maize	8.600c	6.000cd	7.300c
Agrinawa+Maize	3.067de	2.267e	2.667d
Mean	10.239a	9.939a	10.089
	2006/07 Growing season		
PAN311 Mono	16.167a	16.200a	16.183a
Glenda Mono	12.567cd	10.700e	11.633c
Agrinawa Mono	14.500ab	15.067ab	14.783ab
PAN311+Maize	15.667a	15.533a	15.600ab
Glenda+Maize	8.467f	11.000de	9.733d
Agrinawa+Maize	13.700bc	14.767ab	14.233b
Mean	13.511a	13.878a	13.694

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

4.3.2.3. Cowpea seed per pod

Effects of the cropping system was significant for both seasons at Bethlehem (Table 3- Appendix B). In the 2005/06 season, PAN311 and Glenda mono crops produced significantly more seeds per pod (14 and 12, respectively) compared to other cropping systems. In 2006/07 season, only PAN311 produced significantly more seeds per pod (14), both as mono and intercrop. Again on this parameter, the short duration cultivar (PAN311) seemed to have escaped the limited rainfall during season as it matured earlier and produced more number of seeds per pod. Agrinawa and Glenda intercrops statistically produced the same number of seeds per pod during both seasons and there was a 23.8% increase in number of seeds per pod in the second season compared to the first season. This is another indication that cowpea as a drought tolerant crop perform better under harsher conditions.

The cropping system effect was significant for both seasons at Potchefstroom and the interaction effect was significant for the 2006/07 season (Table 3- Appendix B). This is because Potchefstroom is more cry and warmer compared to Bethlehem and the significant interaction effect was influenced by even drier conditions during the 2006/07 season. During the 2005/06 season, PAN311 monocrop produced significantly more seeds per pod (14) and this was reduced to 11 seeds per pod under intercropping (Table 4.8). During this season intercropping significantly reduced cowpea number of seeds per pod with the exception of Agrinawa, which had the lowest number. During the 2006/07 season, Glenda intercrop produced significantly less seeds per pod (5) while PAN311 monocrop remained the highest with 14 seeds per pod. In general, there was a 30.5% increase in number of seeds per pod in the second season compared to the first season. Generally, for the two seasons at both localities, it was clear that different cropping system mainly affected number of seeds per pod, and PAN311 generally produced more seeds per pod both under sole and intercropping conditions. At both locations, Glenda and Agrinawa intercrops produced the same number of seeds per pod while under sole cropping conditions seeds per pod were reduced with increasing growth duration. Chemeda (1997) did not find any difference between sole and intercropped beans as regards to the number of seeds per pod and between different genotypes. It was also reported that intercropping reduces the number of seeds per pod compared to sole cropping (Ndakidemi & Dakora, 2007). Low seed number per pod compensated in the form of bigger seed size from assimilates channeled during ovule formulation and seed development as observed in common bean (Scarisbrick *et al*., 1977 and Ndakidemi & Dakora, 2007).

Table 4.8 The effect of cowpea cropping system and weed infestation on cowpea seed per pod for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Seed per pod		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	13.300ab	14.800a	14.050a
Glenda Mono	12.700ab	11.333bc	12.017a
Agrinawa Mono	7.200de	7.967de	7.583b
PAN311+Maize	9.333cd	6.667e	8.000b
Glenda+Maize	7.433de	6.033e	6.733b
Agrinawa+Maize	7.300de	8.767cde	8.033b
Mean	9.5444a	9.2611a	9.403
	2006/07 Growing season		
PAN311 Mono	14.333a	14.333a	14.333a
Glenda Mono	10.333cd	9.333d	9.833c
Agrinawa Mono	9.333d	10.333cd	9.833c
PAN311+Maize	13.667ab	14.000a	13.833a
Glenda+Maize	11.000cd	12.000bc	11.500b
Agrinawa+Maize	10.333cd	10.667cd	10.500bc
Mean	11.500a	11.778a	11.639
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	13.700ab	15.167a	14.433a
Glenda Mono	12.400abc	10.300c	11.350b
Agrinawa Mono	2.867de	4.133de	3.500c
PAN311+Maize	10.933bc	12.033bc	11.483b
Glenda+Maize	3.467de	4.667d	4.067c
Agrinawa+Maize	2.700de	1.500e	2.100c
Mean	7.6778a	7.9667a	7.822
	2006/07 Growing season		
PAN311 Mono	13.633ab	14.867a	14.250a
Glenda Mono	9.733cd	8.233de	8.983c
Agrinawa Mono	9.367cde	9.867c	9.617c
PAN311+Maize	13.367ab	12.467b	12.917b
Glenda+Maize	5.567f	8.200de	6.883d
Agrinawa+Maize	8.033e	9.167cde	8.600c
Mean	9.950a	10.467a	10.208

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

4.3.2.4. Cowpea 100 seed mass

At Bethlehem during the 2005/06 season, the cropping system effect was significant while in the 2006/07 season only the cropping system effect was observed (Table 3- Appendix B). During the 2005/06 season, PAN311 sole and intercrop in the absence of weeds produced 100 seed masses of 14.000 and 13.667 g and sole crop under weed infestation produces 13.933 g (Table 4.9). PAN311 and Agrinawa intercrops as well as Agrinawa monocrop are the treatments, which significantly contributed to increased mass under no weed infestation. This might be as a result the least number of seeds per pod, which were produced by these two cultivars that resulted in more 100 seed mass. During this season weed infestation reduced the 100 seed mass by 6.1% and PAN311 monocrop treatment generally produced the highest mass of 13.967 g. The lowest mass was observed with Agrinawa sole and intercropping as well as with PAN311 intercropping. During the 2006/07 season, Agrinawa sole and intercropping significantly produced the highest masses (15.667 and 16.050 g) while the other cropping systems were not significant from one another. This was also similar to Potchefstroom during the same season. At Bethlehem there was a 20.3% increase in mass during the 2006/07 season compared to the first season. The harsher conditions of 2006/07 season with the average rainfall below that of 2005/06 season seemed to have also favoured cowpea 100 seed mass.

At Potchefstroom, significant differences were observed for cropping system, weed infestation and interaction effect during the 2006/07 season but only for the cropping system effect during the 2005/06 season (Table 3- Appendix B). During the 2005/06 season, PAN311 and Agrinawa sole and intercropping, produced significantly higher 100 seed mass and the lowest mass (12.917 g) was observed with Glenda intercrop (Table 4.9). During the 2006/07 season, Agrinawa intercrop, in the absence of weeds, produced significantly higher mass (18.133 g) and this was significantly reduced to 15.700 g under weed infestation. Generally at Bethlehem, PAN311 sole and Agrinawa intercrop, significantly produced the highest mass while the lowest was observed with PAN311 intercrop. At Potchefstroom, Agrinawa sole and intercrop significantly produced the highest 100 seed mass (15.558 and 15.342 g) while other cropping systems were not significantly different from one another. Agrinawa intercrop was the only treatment, which 100 seed mass was significantly reduced by weed infestation. Chemeda (1997) did not find any significant difference between sole and intercropped beans on 100 seed mass but there were differences among different genotypes. Wright (1981) reported higher 100 seed mass of soybean under intercropping than sole cropping conditions.

Table 4.9 The effect of cowpea cropping system and weed infestation on cowpea 100 seed mass (g) for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	100 seed mass (g)		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	13.933a	14.000a	13.967a
Glenda Mono	12.000b	12.067b	12.033b
Agrinawa Mono	10.467e	11.400cd	10.933c
PAN311+Maize	10.533e	13.667a	12.100b
Glenda+Maize	12.200b	11.900bc	12.050b
Agrinawa+Maize	10.633e	11.300d	10.967c
Mean	11.628b	12.389a	12.001
	2006/07 Growing season		
PAN311 Mono	13.800cd	13.633cd	13.717b
Glenda Mono	15.033abc	12.900d	13.967b
Agrinawa Mono	15.433ab	15.900a	15.667a
PAN311+Maize	13.300d	13.233d	13.267b
Glenda+Maize	14.267bcd	13.633cd	13.950b
Agrinawa+Maize	15.933a	16.167a	16.050a
Mean	14.628a	14.244a	14.436
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	13.667abc	14.000abc	13.833ab
Glenda Mono	13.367bc	12.867bc	13.117b
Agrinawa Mono	14.033abc	15.500a	14.767a
PAN311+Maize	14.333abc	14.667ab	14.500a
Glenda+Maize	13.167bc	12.667c	12.917b
Agrinawa+Maize	13.167bc	14.367abc	13.767ab
Mean	13.622a	14.011a	13.816
	2006/07 Growing season		
PAN311 Mono	11.833cde	12.933c	12.383b
Glenda Mono	12.600cd	12.367cde	12.483b
Agrinawa Mono	16.367b	16.333b	16.350a
PAN311+Maize	11.967cde	11.300de	11.633b
Glenda+Maize	11.167e	12.233cde	11.700b
Agrinawa+Maize	15.700b	18.133a	16.917a
Mean	13.272b	13.883a	13.577

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

4.3.2.5. Cowpea pod mass

Cowpea pod mass was significantly affected by both all the main and interaction effects during both seasons at Bethlehem (Table 3- Appendix B). During both seasons, cowpea pod mass was significantly reduced by intercropping and weed infestation (Table 4.10). During the 2005/06 season, Glenda monocrop produced significantly higher pod yield (1 813.3 kg ha^{-1}) while PAN311 intercrop produced the lowest pod yield (190.5 kg ha^{-1}). Similar responses under no weed infestation treatments were also observed during the 2005/06 season. During the 2006/07 season PAN311 monocrop produced the highest yield (1 671.1 kg ha^{-1}) and the lowest (775.4 kg ha^{-1}) under intercropping. Similar responses were also observed under no weed infestation conditions. At Bethlehem there was a 33.1% increase in pod mass in the second season compared to the first season. Weed infestation caused a significant 27.9 and 26.9% reduction in pod mass during the 2005/06 and 2006/07 seasons, respectively and the intercrop treatments produced lower yield than sole crops. Cowpea as a drought tolerant crop produces more yield under limited rainfall conditions (2006/07 season) unlike in high rainfall (2005/06 season).

At Potchefstroom, only the interaction effect was non-significant during the 2005/06 season while both the main effects were significant (Table 3- Appendix B). During both seasons, PAN311 monocrop produced highest pod yields (2 007.6 and 1 97.23 kg ha^{-1}) for the first and second seasons, respectively (Table 4.10). There was a 31.8% and 14.6% by weed infestation during the 2005/06 and 2006/07 seasons, respectively, compared to no weed infestation. Contrary to Bethlehem, at Potchefstroom there was a 45.2% decrease in pod mass in the 2006/07 season compared to the 2005/06 season. This could probably be attributed to reduced number of pods per plant during the 2006/07 season and it seemed to be more affected under warmer and drier conditions.

On average for the two seasons at both locations, cowpea pod mass was reduced with increasing growth duration as was the case with sole and intercropping conditions. At Bethlehem, Glenda monocrop treatment performed better while at Potchefstroom it was PAN311 monocrop. At Bethlehem the lowest pod yield was obtained with PAN311 intercrop in the absence of weeds while at Potchefstroom, the lowest yield was measured with Glenda intercrop under weed infestation. PAN311 and Glenda monocrops at Bethlehem were generally the only treatments, which pod mass was significantly reduced by weed infestation while at Potchefstroom, only PAN311 monocrop was significantly affected.

Table 4.10 The effect of cowpea cropping system and weed infestation on cowpea pod mass (kg ha^{-1}) for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Pod mass (kg ha^{-1})		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	963.9cde	1480.1b	1222.0b
Glenda Mono	1417.9bc	2208.6a	1813.3a
Agrinawa Mono	891.3def	1072.1bcd	981.7bc
PAN311+Maize	294.1gh	87.0h	190.5e
Glenda+Maize	711.8defg	488.8efgh	600.3cd
Agrinawa+Maize	207.9h	415.3fgh	311.6de
Mean	747.82b	958.67a	853.24
	2006/07 Growing season		
PAN311 Mono	1000.4c	2341.9a	1671.1a
Glenda Mono	963.4c	1839.7b	1401.6b
Agrinawa Mono	1059.2c	1147.4c	1103.3c
PAN311+Maize	848.8c	702.0c	775.4d
Glenda+Maize	863.9c	955.3c	911.6cd
Agrinawa+Maize	883.5c	712.7c	798.1d
Mean	937.2b	1283.2a	1110.20
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	1432.1bc	2583.1a	2007.6a
Glenda Mono	1164.5bcd	1653.6b	1409.0b
Agrinawa Mono	620.1def	632.2def	626.1c
PAN311+Maize	998.1cde	1278.6bc	1138.3b
Glenda+Maize	373.4f	682.8def	528.1c
Agrinawa+Maize	562.1ef	728.6def	645.4c
Mean	858.4b	1259.8a	1059.10
	2006/07 Growing season		
PAN311 Mono	1329.8a	1464.6a	1397.2a
Glenda Mono	590.4bc	639.8b	615.1b
Agrinawa Mono	296.5cde	641.9b	469.2bc
PAN311+Maize	521.7bcd	457.5bcde	489.6bc
Glenda+Maize	301.4cde	254.8de	278.1c
Agrinawa+Maize	163.5e	295.1cde	229.3c
Mean	533.88b	625.62a	579.75

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

4.3.2.6. Cowpea grain yield

All the treatment effects were significant for cowpea grain yield during both seasons at Bethlehem (Table 3- Appendix B). During the 2005/06 season, only Glenda's yield was significantly reduced by weed infestation, but with Glenda monocrop having the highest mean yield of 1 309.6 kg ha^{-1}. PAN311 intercrop produced the lowest mean yield of 122.8 kg ha^{-1} (Table 4.11). Similar responses were also observed under zero weed infestation treatments. In the 2005/06 season, weed infestation caused a 32.5% grain yield reduction compared to no weed infestation. During the 2006/07 season, PAN311 monocrop produced the highest mean yield (1 176.8 kg ha^{-1}) while the lowest yield (575.1 kg ha^{-1}) was produced by Agrinawa intercrop. Under weed-free treatments similar responses were observed. During the 2006/07 season, weed infestation resulted in a 21.9% reduction in grain yield, with yield responses of PAN311 and Glenda monocrops making significant contributions to this effect.

At Potchefstroom, no interaction effect was observed during both seasons while the cropping system and weed infestation effects were significant (Table 3- Appendix B). During the 2005/06 and 2006/07 seasons, PAN311 monocrop produced significantly higher mean grain yields (1 229.6 and 1 205.1 kg ha^{-1}, respectively) (Table 4.11). This is because PAN311 has high number of pods per plant, longer pod lengths and more number of seeds per pod. During the 2005/06 season, weed infestation reduced cowpea grain yield by 29.2% while there was a 20.9% reduction during the 2006/07 season. PAN311 monocrop was the only treatment at which grain yield was significantly reduced by weed infestation during both seasons. PAN311 produced significantly the least leaf and total DMY and there was a resultant high weed biomass, which probably competed strongly for growth resources. At Bethlehem, there was a 49.6% increase in grain yield in the second season compared to the first season while a 34.9% decrease in the second season compared to the first season was observed at Potchefstroom. Chemeda (1997) also found that different bean genotypes differ in their seed yield. Different genotypes behave differently under different cropping systems and may also vary in their ability to compete with maize for growth resources in addition to the shading affect (Willey & Osiru, 1972; Woolley & Rodriquez, 1987 and Chemeda, 1997). According to Mpangane *et al*. (2004), the short duration cultivar, PAN311, was the only cultivar whose seed yield was reduced by intercropping with maize while the medium and long duration cultivars produced similar yields under both cropping systems.

Table 4.11 The effect of cowpea cropping system and weed infestation on cowpea grain yield (kg ha^{-1}) for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Grain yield (kg ha^{-1})		
	Weeds	Zero weeds	
Cropping System	2005/06 Growing season		Mean
PAN311 Mono	618.4bc	765.9b	692.1b
Glenda Mono	727.4b	1891.7a	1309.6a
Agrinawa Mono	532.0bcd	656.0b	594.0bc
PAN311+Maize	182.5ef	63.1f	122.8d
Glenda+Maize	457.1bcde	269.8cdef	363.5cd
Agrinawa+Maize	105.6f	243.5efg	174.5d
Mean	437.17b	648.33a	542.75
	2006/07 Growing season		
PAN311 Mono	767.3b	1586.3a	1176.8a
Glenda Mono	734.7b	1301.7a	1018.2a
Agrinawa Mono	798.7b	811.3b	805.0b
PAN311+Maize	695.3b	524.6b	609.9c
Glenda+Maize	624.5b	751.8b	688.2bc
Agrinawa+Maize	654.0b	496.1b	575.1c
Mean	712.42b	911.97a	812.19
Potchefstroom			
	2005/06 Growing season		
PAN311 Mono	971.6bc	1487.6a	1229.6a
Glenda Mono	781.3bcd	1106.4b	943.9b
Agrinawa Mono	357.7e	458.5de	408.1c
PAN311+Maize	706.5cd	855.3bc	780.9b
Glenda+Maize	282.7e	450.1de	366.4c
Agrinawa+Maize	338.4e	497.7de	418.1c
Mean	573.03b	809.28a	691.15
	2006/07 Growing season		
PAN311 Mono	1069.4b	1340.7a	1205.1a
Glenda Mono	363.2cd	498.9c	431.0b
Agrinawa Mono	218.4cd	392.3cd	305.4b
PAN311+Maize	372.6cd	365.5cd	369.1b
Glenda+Maize	235.3cd	180.6d	207.9b
Agrinawa+Maize	125.9d	237.8cd	181.8b
Mean	397.47b	502.64a	450.05

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

Generally, cowpea grain yield decreased with increasing growth duration and at Bethlehem cowpea grain yield was higher than at Potchefstroom. There was a 63.9 and 52.7% reduction in PAN311 grain yield under intercropping at Bethlehem and Potchefstroom, respectively, compared to sole cropping. Reduced legume yield under intercropping was also reported by Chemeda (1997) with maize-bean intercropping, which was associated with reduced number of pods per plant and seed per pod. Less seed yield under intercropping in the present study differs from the results of Adeniyan *et al*. (2007) who found more yield by African yam bean when intercropped with maize. Factors such as water stress, light quality and shading are among the factors that affect crop yields and yield components at different crop growth stages (Leisong & Francis, 1999), thus shading of soybean plants causes abscission of flower and pods (Mann & Jawoski, 1970).

On average for the two seasons it can be concluded that the medium growth cowpea cultivar, Glenda, as monocrop performed better at Bethlehem while the short duration cultivar PAN311 as monocrop performed better at Potchefstroom. The short duration cultivar (PAN311) produced more pods per plant under warmer and drier conditions while the medium duration cultivar (Glenda) produced more pods per plant under cooler and wetter conditions. PAN311 managed to escape dry conditions of Potchefstroom while Glenda was more adapted to cooler and wetter conditions of Bethlehem. At both locations, weed infestation caused a significant reduction in cowpea grain yield regardless of the seasonal variation. PAN311 and Glenda monocrops at Bethlehem and PAN311 monocrop at Potchesftroom contributed significantly to reduced grain yield under weed infestation.

4.3.3. Correlation analysis

4.3.3.1. Maize correlations

Maize grain yield was significantly correlated to ear mass during both seasons at both localities (Table 4.12). There also was a correlation between grain yield and number of ears per plant, especially during the 2006/07 season at both locations while no significant correlations were observed during the 2005/06 season. The 100 seed mass was significantly correlated to grain yield at Bethlehem but not at Potchefstroom. Significant correlation was also observed with ear length during the 2006/07 season at Bethlehem and with the number of seeds per ear at Potchefstroom during the same season. On average for the two seasons, it was clear that the number of ears per plant and ear mass significantly influenced maize grain yield at both locations. Besides these parameters, Bavec & Bavec (2001 & 2002), found a strong correlation between maize leaf area and grain yield. Thwala & Ossom (2004) reported a significant positive correlation between cob length and grain yield while a negative non-significant correlation was reported between number of kernels per row and grain yield. Ofori & Stern (1986) reported that the main determinant of grain yield was the number of seeds m^{-2}.

Table 4.12 Coefficient of determination (r^2) values for maize yield parameters against final grain yield for 2005/06 and 2006/07 at Bethlehem and Potchefstroom.

Growing season	Total DMY (kg ha^{-1})	Ear number per plant	Ear length (cm)	Seed per ear	100 seed mass (g)	Ear mass (kg ha^{-1})
			Bethlehem			
2005/06	0.4004^{ns}	0.2548^{ns}	-0.2075^{ns}	-0.1349^{ns}	0.5359^{**}	0.9896^{**}
2006/07	0.1397^{ns}	0.8319^{**}	0.5262^{**}	0.3579^{ns}	0.5493^{**}	0.9971^{**}
Mean	0.2266^{ns}	0.6991^{**}	0.4325^{*}	0.4100^{*}	0.6443^{**}	0.9957^{**}
			Potchefstroom			
2005/06	0.0312^{ns}	0.4557^{*}	0.2828^{ns}	0.2075^{ns}	0.3651^{ns}	0.9945^{**}
2006/07	0.5162^{**}	0.6111^{**}	0.4312^{*}	0.5256^{**}	0.1555^{ns}	0.9758^{**}
Mean	0.3710^{ns}	0.5373^{**}	0.3881^{ns}	0.4557^{*}	0.2818^{ns}	0.9863^{**}

** = Highly significant; * = Significant; NS = Non significant.

4.3.3.2. Cowpea correlations

At Bethlehem pods per plant, seeds per pod and pod mass were highly significantly correlated with grain yield in the 2005/06 season, but in the 2006/07 season, only pod mass was significantly correlated with grain yield (Table 4.13). Pod mass was best correlated with grain yield followed by number of pods per plant. At Potchefstroom, much better correlations were obtained between number of pods per plant, pod length, seeds per pod, pod mass and grain yield. Pod mass was again most strongly correlated with grain yield. Total DMY was only correlated weakly with grain yield at Bethlehem in 2005/06, and unexpectedly, 100 seed mass was in no instance correlated with grain yield. This suggests that pod mass was the best variable from which grain yield could be derived. Ofori & Stern (1986) reported that the number of pods m^{-2} were the main determinants of cowpea grain yield.

Table 4.13 Coefficient of determination (r^2) values for cowpea yield parameters against final grain yield for 2005/06 and 2006/07 at Bethlehem and Potchefstroom.

Growing season	Total DMY (kg ha^{-1})	Pod per plant	Pod length (cm)	Seed per pod	100 seed mass (g)	Pod mass (kg ha^{-1})
			Bethlehem			
2005/06	0.4042*	0.4987**	0.3692*	0.4847**	0.1578^{ns}	0.9470**
2006/07	-0.1134^{ns}	0.3368*	-0.1235^{ns}	0.0935^{ns}	-0.2658^{ns}	0.9838**
Mean	0.2377^{ns}	0.4289**	0.2193^{ns}	0.3295*	-0.0141^{ns}	0.9713**
			Potchefstroom			
2005/06	-0.3199^{ns}	0.8048**	0.6872**	0.7861**	-0.0028^{ns}	0.9675**
2006/07	-0.0235^{ns}	0.6523**	0.4136*	0.6856**	-0.2821^{ns}	0.9804**
Mean	-0.1831^{ns}	0.8710**	0.7127**	0.7908**	-0.2835^{ns}	0.9873**

** = Highly significant; * = Significant; NS = Non significant.

4.3.4. Land Equivalent Ratio (LER) values for maize and cowpea grain yield

At both locations and seasons, no intercropping advantage was observed on cropping system and weed infestation (total LER< 1). However, during both seasons at Bethlehem, LER values, which give an indication of land use efficiency, increased under weed infestation compared to zero weed treatments (Table 4.14). With the exception of Glenda and Agrinawa as intercrops in 2005/06 season, the ratios of maize intercrop yields/sole maize yields are much larger under weed infestation compared to weed free conditions. This means that maize yields, when intercropped with cowpeas and in the presence of weeds, decrease less from sole maize compared to weed free conditions. This effect was much more pronounced at Bethlehem. Increased total LER during 2006/07 was as a result of 54.2% increase in maize grain yield under intercropping with PAN311 compared to sole cropping in the presence of weeds (Table 4.5). This resulted in maize partial LER of 0.77 under weed infestation compared to 0.45 under zero weed infestation when intercropped with PAN311 (Table 4.15).

The same trend was observed with cowpea grain yields, for example, during the 2005/06 season, there was a 37.1% yield reduction of Glenda when intercropped in the presence of weeds compared to a 85.7% reduction under zero weed conditions. This in turn favoured total LER under weed infestation conditions where Glenda produced partial LER's of 0.31 and 0.07 under weed infestation and zero weeds, respectively (Table 4.15). During the 2006/07 season PAN311 intercropped with maize (1.22) contributed significantly to increased total LER under weed infestation.

There was a 9.4 and 66.9% reduction in PAN311 intercrop yields under weed infestation and no weed infestation, respectively, which contributed significantly to a high LER. This might also be related to the lack of significant differences between sole and intercropped Glenda grain yield during the 2005/06 season under weed infestation (Table 4.11). Therefore, larger intercrop/sole ratios resulted in higher LER values for intercropping systems in the presence of weeds.

Table 4.14 The effect of maize-cowpea intercropping system and weed infestation on grain yield's total LER for the 2005/06 and 2006/07 growing seasons at Bethlehem and Potchefstroom.

Bethlehem	Total LER for Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.61	0.46	0.54
Glenda+Maize	0.69	0.50	0.60
Agrinawa+Maize	0.47	0.59	0.53
Mean LER	0.59	0.52	
	2006/07 Season		
PAN311+Maize	1.22	0.62	0.92
Glenda+Maize	0.95	0.66	0.81
Agrinawa+Maize	0.81	0.60	0.71
Mean LER	0.99	0.63	
Potchefstroom	Total LER for Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.77	0.66	0.58
Glenda+Maize	0.55	0.58	0.57
Agrinawa+Maize	0.93	0.96	0.95
Mean LER	0.75	0.73	
	2006/07 Season		
PAN311+Maize	0.41	0.36	0.39
Glenda+Maize	0.57	0.52	0.55
Agrinawa+Maize	0.37	0.54	0.46
Mean LER	0.45	0.47	

Table 4.15 The effect of intercropping system and weed infestation on maize and cowpea grain yield partial LER for the 2005/06 and 2006/07 growing seasons at Bethlehem.

Maize	Partial LER for Maize Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.46	0.42	0.44
Glenda+Maize	0.38	0.43	0.41
Agrinawa+Maize	0.37	0.41	0.39
Mean LER	0.40	0.42	
	2006/07 Season		
PAN311+Maize	0.77	0.45	0.61
Glenda+Maize	0.52	0.37	0.45
Agrinawa+Maize	0.40	0.29	0.35
Mean LER	0.56	0.37	
Cowpea	Partial LER for Cowpea Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.15	0.04	0.10
Glenda+Maize	0.31	0.07	0.19
Agrinawa+Maize	0.10	0.18	0.14
Mean LER	0.79	0.10	
	2006/07 Season		
PAN311+Maize	0.45	0.17	0.31
Glenda+Maize	0.43	0.29	0.36
Agrinawa+Maize	0.41	0.31	0.36
Mean LER	0.43	0.26	

Under warmer and drier conditions at Potchefstroom, similar results to those of Bethlehem were observed during the 2005/06 season but the opposite was observed in the 2006/07 season (Table 4.14). During the 2006/07 season, there were no significant differences between sole and intercropped Agrinawa yield, both under weed and zero weed infestation treatments. On average, Agrinawa as intercrop resulted in the lowest effect on LER between weed and zero weed treatments, however, maize grain yield was significantly reduced by Agrinawa intercropping under weed infestation, which produced the lowest yield during the 2006/07 season (Table 4.5).

Table 4.16 The effect of intercropping system and weed infestation on maize and cowpea grain yield's partial LER for the 2005/06 and 2006/07 growing seasons at Potchefstroom.

Maize	Partial LER for Maize Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.41	0.37	0.39
Glenda+Maize	0.37	0.38	0.38
Agrinawa+Maize	0.46	0.42	0.44
Mean LER	0.41	0.39	
	2006/07 Season		
PAN311+Maize	0.24	0.22	0.23
Glenda+Maize	0.25	0.34	0.30
Agrinawa+Maize	0.08	0.24	0.16
Mean LER	0.19	0.27	
Cowpea	Partial LER for Cowpea Grain Yield		
	Weeds	Zero weeds	
Cropping System	2005/06 Season		Mean LER
PAN311+Maize	0.36	0.29	0.33
Glenda+Maize	0.18	0.20	0.18
Agrinawa+Maize	0.47	0.54	0.51
Mean LER	0.34	0.34	
	2006/07 Season		
PAN311+Maize	0.17	0.14	0.16
Glenda+Maize	0.32	0.18	0.25
Agrinawa+Maize	0.29	0.30	0.30
Mean LER	0.26	0.21	

Higher LER values under weed infestation were also reported by Weil & McFadden (1991) who attributed this to stress effects, which favoured intercropping conditions. Under wetter and cooler conditions, PAN311 and Glenda intercropping with maize contribute significantly to high total LER's in the presence of weeds. Light is the most important factor determining LER of maize and cowpea intercropping and LER declines when the legume becomes severely shaded (Ofori & Stern, 1986 and Davis *et al*., 1984). From results it seems as if cowpea was the main determinant of LER. According to Ofori & Stern (1986), when cowpea becomes severely suppressed and maize growth is increased, LER values becomes lower due to reduced cowpea yields. Similar responses on grain yields for maize and cowpea were observed at Bethlehem, especially under no weed infestation. Tsubo *et al*. (2003) reported that maize LER increases from low to medium density and decreases from medium to high density, but that bean partial LER decreases with increasing bean plant density. A total LER less than 1 of the cropping system indicates that for better use of land maize and cowpea are to be sown as sole crops rather than as intercrops for maximum yields at these locations. This differs with the findings of Olufajo (1992) and Agbeje, Ogunbodede & Makinde (2002) who reported an intercropping advantage over sole cropping because of high intercropping yield compared to sole cropping. The differences could be attributed to the fact that, these authors conducted their studies under high rainfall areas, which ranges from 1500-1750 mm per annum, whereas in this study, the annual rainfall was between 650-750 mm.

4.3.5. Soil and plant nitrogen analysis

4.3.5.1. Soil Analysis

At Potchefstroom during the 2006/07 season, no significant differences were observed in soil ammonium content (NH_4^+) as affected by the cropping systems, while nitrate (NO_3^-) and total inorganic N were only significantly affected by weed treatment (Table 5-Appendix B). NO_3^--N was reduced by 47.7% in weed-infested treatments compared to no weed infestation. This is because nitrate is the major N-source absorbed by plants (Crawford, 1995). Maize intercropped with Agrinawa in the absence of weeds produced the highest levels of NO_3^--N (5.5167 mg/kg), which was significantly reduced (2.3500 mg/kg) under weed infestation (Table 4.17). The lowest level of nitrate was observed with Agrinawa monocrop (1.7333 mg/kg) under weed infestation. Higher amounts of NO_3^--N under Agrinawa treatments, especially under intercropping, could be attributed to its long growth duration, which could have resulted in more decomposition of plant materials thus producing more N.

Even though grain legumes are widely used for intercropping due to their N_2-fixation ability, consequent benefit for the companion crops in intercropping is rarely reported (Senaratne *et al*., 1995). According to Ta & Francis (1987), N_2-fixation and transfer differs with different legume species and it was found that alfalfa and red clover excreted more N during the growing season while trefoil produced more N from the decomposition of dead nodule and root tissues. Ayisi & Mpangane (2004) mentioned that the importance of legume variety as intercrops in parts of South Africa, including the Limpopo province, is yet to be documented, especially with regard to N_2-fixation. Some cowpea cultivars respond differently to symbiotic activity as sole crops (Ayisi *et al*., 2000). Under fertilized plots, Horst & Hardter (1994) found more nitrate under sole crop conditions when maize was rotated with cowpeas and this attributed to reduced maize root length density under sole crop compared to crop rotations. This might also be the case with nitrate and total N under maize sole crop, which was higher than for some legumes under sole and intercropping conditions.

Table 4.17 Mean values for soil NH_4^+N and NO_3^-N in cowpea cropping systems as affected by weed infestation at Potchefstroom for the 2006/07 season.

	Soil N (mg/kg)			
Treatments	Weeds	No Weeds	Weeds	No Weeds
	NH_4^+-N		NO_3^--N	
Maize Mono	1.0333ab	0.7833ab	2.1000e	4.3000ab
PAN311 Mono	0.8500ab	0.7000b	1.9000e	3.1333bcde
Glenda Mono	1.1167a	0.8167ab	2.1833de	4.0500abcd
Agrinawa Mono	0.7333ab	0.8167ab	1.7333e	4.4667ab
Maize+PAN311	0.9833ab	0.9167ab	2.6500bcde	4.6833ab
Maize+Glenda	0.8667ab	0.8333ab	2.9667bcde	4.2167abc
Maize+Agrinawa	0.9500ab	0.8667ab	2.3500cde	5.5167a
Mean	0.9333a	0.8190a	2.2690b	4.3381a

Means followed by the same letters within a column and a row at each soil N are not significantly different at $P< 0.05$.

Similar to NO_3^--N, total soil N was significantly reduced by 37.9% under weed infestation compared to zero weed (Table 4.18). A similar response to NO_3^--N was also observed for total soil N where maize intercropped with Agrinawa (6.8333 mg/kg) in the absence of weeds produced the highest levels and Agrinawa monocrop in the absence of weeds the lowest (2.4667 mg/kg). Agrinawa mono and intercrop were the two treatments that significantly contributed to reduced total soil N due to weed infestation. The total inorganic N comprises of nitrate and ammonia (Table 4.18).

On the other hand, soil organic N is contributing to the inorganic source through the decomposition of organic matter (e.g. urea) and it is available to plants in very small quantities of 1- 3% through mineralisation (Harper, 1984 and Ladd, 1990).

Table 4.18 Mean values for total soil N ($NH_4^+N + NO_3^-N$) in cowpea cropping systems as affected by weed infestation at Potchefstroom for the 2006/07 season.

	Total Soil N (mg/kg)		
Treatments	Weeds	No Weeds	Mean
Maize Mono	3.1333de	5.0833abcd	4.1083ab
PAN311 Mono	2.7500e	3.8333bcde	3.2917b
Glenda Mono	3.3000cde	4.8667abcd	4.0833ab
Agrinawa Mono	2.4667e	5.2833abc	3.8750ab
Maize+PAN311	3.6333bcde	5.6000ab	4.6167a
Maize+Glenda	3.8333bcde	5.0500abcd	4.4417ab
Maize+Agrinawa	3.3000cde	6.3833a	4.8417a
Mean	3.2024b	5.1571a	

Means followed by the same letters with a column and a row are not significantly different at $P< 0.05$.

4.3.5.2. Plant analysis

Maize and cowpea plant nitrogen content was only analysed for the weed-free treatments while weed samples were collected from weedy treatments but no significant differences were observed between the samples (Table 6- Appendix B). The lack of significant differences in maize, cowpea and weed samples at this locality might be an indication that different growth duration cultivars exhibit similar responses to N_2 fixation, especially under sole cropping conditions. The mean N for maize, cowpeas and weed samples were 1.75%, 4.36% and 1.87 %, respectively.

4.3.6. Summary and conclusions

Different maize yield parameters responded to cropping system and weed infestation effects. Under the cooler and wetter conditions of Bethlehem, maize 100 seed mass was significantly reduced by weed infestation during both seasons. Maize ear and grain yield were significantly affected by cropping system with maize as monocrop giving higher yield compared to the intercrop treatments. The significant yield reduction by weed infestation on grain yield was observed during the second season. During the 2006/07 season, maize monocrop and maize intercropped with PAN311 had significantly more ears per plant than maize intercropped with Agrinawa. Under the dry and warmer conditions of Potchefstroom, maize monocrop treatment gave significantly higher ear and grain yields while both were reduced through weed infestation. Superior ear and grain yield by sole maize was contributed by larger ear length, especially in the absence of weeds. In general, maize ear length was significantly affected by weed infestation and the interaction effect, while ear mass was only affected by intercropping. The maize yield component that was most strongly correlated with maize grain yield was the ear mass. The number of ears per plant at both locations and the 100 seed mass at Bethlehem also had a significant correlation with maize grain yield. Maize performed better if planted as sole crop in the absence of weeds at both locations and most preferably at Bethlehem because of higher yields. Similar results of reduced maize yield under intercropping and weed infestation were also reported by Silwana & Lucas (2002).

Cropping system and weed infestation affected different cowpea yield parameters. Under wetter and cooler conditions of Bethlehem, Glenda and Agrinawa monocrops produced the largest number of pods per plant and weed infestation caused a 23.7% reduction during the drier season of 2006/07. Under drier and warmer condition at Potchefstroom, PAN311 monocrop produced more pods per plant and weed infestation had a significant reduction in all the treatments. Generally, during both seasons at both locations, PAN311 monocrop produced the longest pods and number of seeds per pod. Under cooler and wetter conditions, 100 seed mass varied between cropping season and weed infestation. Under warmer and drier conditions, especially during the second season, Agrinawa produced significantly more 100 seed mass. Significant 100 seed mass reduction by weed infestation was observed during the first and second season at Bethlehem and Potchefstroom, respectively.

Under cooler and wetter environments, Glenda monocrop produced significantly higher grain yield. The superior yield of Glenda monocrop was probably due to more pods per plant produced during especially the 2005/06 season. Under warmer and drier conditions, PAN311 produced significantly more grain yield, which might be attributed to more pods per plant, increased pod length and number of seeds per pod. Generally, weed infestation significantly reduced cowpea grain yield at both locations. Pod mass at Bethlehem was the only yield component that had a strong correlation with grain yield. At Potchefstroom, the number of pods per plant, pod length and the number of seeds per pod were the yield components correlated with cowpea grain yield. From the results it can be concluded that Glenda and PAN311 monocrops must be planted for more grain yield at Bethlehem and Potchefsteroom, respectively. Higher legume grain yield under sole cropping compared to intercropping were also reported by Chemeda (1997). Water stress and shading are probably the two major factors, which contributed to reduced cowpea yield under intercropping (Leisong and Francis, 1999).

During both seasons LER values increased under weed infestation compared to zero weed infestation especially under wetter and cooler environments. Similar results of higher LER under weed infestation were also observed by Weil & McFadden (1991). On average it appeared that the LER value decreased with increasing growth duration of the cowpea under weed infestation while the opposite was observed under weed-free treatments. LER less than 1 observed during both seasons implies that maize and cowpea should be planted as sole crops for better yields at both locations. The plant nitrogen analysis at Potchefstroom indicated no nitrogen content differences between maize, cowpea and weed samples. The soil nitrate (NO_3^--N) and total soil N were significantly reduced by weed infestation while there were no differences observed on soil ammonium content (NH_4^+-N). It can therefore be concluded that different growth duration cowpea cultivars do not differ in their nitrogen accumulation and nitrate becomes more utilised under weed infestation.

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CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. General discussion

Maize is the third most important cereal crop in the world and many subsistence farmers are practicing intercropping of it with legumes in order to enhance production through efficient use of natural resources (Ayeni, 1987). The differences in vegetative and reproductive growth responses of maize and cowpea between two localities and seasons were affected by different environmental conditions. Under cooler and wetter conditions, which occurred at Bethlehem, maize monocrop and maize intercropped with a long growth season cowpea cultivar produced significantly more LAI. Maize LAI was not affected by any treatment under drier and warmer conditions experienced at Potchefstroom. Treatments did not affect maize total DMY and number of days to 50%-flowering. Cooler and wetter conditions generally promoted the production of higher total DMY compared to warmer and drier conditions. In terms of plant height, maize monocrop and intercropping with medium duration cowpea, produced the tallest plants compared to any other treatment under warmer and drier conditions. Bavec *et al*. (2005) reported an increase in maize plant height and leaf area due to intercropping with climbing beans, while Muoneke, Ogwuche & Kalu (2007) did not find any difference in these parameters due to intercropping.

Taller maize cultivars result in lower yield of intercropped cowpeas, compared to shorter cultivars due to the increased shading effect (Wahua, Babalola & Aken'oven, 1981). Positive correlation was found between plant height and grain yield of maize (Camacho & Caraballo, 1994). Under cooler and wetter conditions, maize 100 seed mass was reduced by weed infestation and thus the ear and grain yield. Under these conditions, more ears per plant were observed with sole maize and maize intercropped with a short duration cowpea cultivar. Under drier and warmer conditions, superior maize yields resulted from greater ear lengths, especially in the absence of weeds. At both locations, intercropping reduced the ear and grain yield with sole maize producing the highest yield. The reduction in maize grain yield under intercropping was also confirmed by Bavec *et al*. (2005). Maize ear mass was strongly correlated with grain yield at both locations and seasons. Number of ears per plant and 100 seed mass were also significantly correlated with grain yield under cooler and wetter conditions. Weed infestation and intercropping significantly reduced number of days to physiological maturity of maize at both locations. Competition for nutrients and especially water could have resulted in the reduction of number of days to maturity of maize when competing with weeds. It is believed that intercropping increases dry matter production and yield compared to sole crops (Fujita *et al*., 1992). Benefits of such systems have also not been reported in some instances (Cenpukdee & Fukai, 1992).

Medium and long duration cowpea cultivars produced more nodules per plant, especially under intercropping conditions compared to short duration cultivars. This might be an indication that cowpea as an inheritably drought tolerant crop, in this way at least, is better adapted to harsher conditions under intercropping than under sole cropping conditions. Leaf DMY and total DMY in general, increased with increasing cowpea growth duration and under drier and warmer conditions. Medium and long duration cowpea leaf DMY was promoted by weed infestation under intercropping conditions. Short duration cultivars may produce less leaf DMY and total DMY because of early flowering, thus minimizing the vegetative growth period compared to long duration growers. Higher DMY production by maize and cowpea treatments in the 2005/06 season was probably due to better rainfall compared to lower yields in the 2006/07 season. This also applied to grain yield for the two seasons at both locations, but biomass production and grain yield at Bethlehem was generally better than at Potchefstroom. This probably was due to more and better distributed rainfall and lower temperatures. Significantly delayed cowpea flowering was observed at Potchefstroom while no such effect was observed at Bethlehem. Intercropping delayed cowpea flowering and physiological maturity at both locations and seasons. This might have been due to the shading effect of maize plants (Mbah, Mouneke & Okpara, 2007) thus reducing light interception by the intercropped cowpeas. This probably resulted in the abscission of flowers, therefore, reducing yield.

Generally, medium and long duration cowpea cultivars produced more pods per plant under cooler and wetter conditions while the short duration cultivar produced more pods per plant under drier and warmer conditions. This implies that these cultivars are only well adapted under specific climatic conditions and that cultivation under no-favourable conditions could result in significant yield reduction. During drier conditions of the 2006/07 season, weed infestation significantly reduced the number of pods per plant at both locations. Mbah *et al.* (2007) and Muoneke *et al.* (2007) reported a reduction in the number of soybean pods per plant and grain yield under intercropping. The greatest pod lengths were also observed with the short duration cultivar as monocrop at both locations. The short duration cowpea cultivar produced the greatest number of seeds per pod at both locations and it was followed by the medium and long duration cultivars and intercropping conditions reduced number of seeds per pod. This resulted in higher yields of the short duration cultivar that was reduced by intercropping conditions.

Under warmer and drier conditions, 100 seed mass was in general reduced by weed infestation and Agrinawa monocrop resulted in significantly more 100 seed mass. This was attributed to lesser number of seeds per pod. The medium and short duration cowpea cultivars as monocrops produced more pod mass, especially in the absence of weeds under cooler and wetter conditions. A similar trend was also observed for grain yield. During both seasons, the short duration cultivar as monocrop produced more pod and grain yield under warmer and drier conditions and both parameters were significantly reduced by weed infestation at both locations. Higher yield by the short duration cultivar was probably due to more seeds produced per pod and longer pods. Cowpea pod mass was strongly correlated to grain yield at both locations and seasons. Number of pods per plant, pod length and the number of seeds per pod were also correlated to grain yield at Potchefstroom.

Weeds species grew better and produced more biomass under warmer and drier conditions at Potchefstroom compared to Bethlehem. Intercropping, especially with medium and long duration cultivars controlled weeds better in terms of growth compared to sole cropping of maize and cowpea. Better control of weeds by intercropping with medium and long duration cultivars could be attributed to more leaf and total DMY production by these cultivars, thus inhibiting the growth and development of weeds through shading and better competition for growth resources (Altieri & Liebman, 1988). Allelopathic effects by cowpeas on weed growth and crop yields might also be one of the contributing factors especially for Glenda and Agrinawa and this was also reported by White *et al*. (1989).

The presence of weeds under intercropping conditions seems to improve the efficient use of land (LER) compared to sole cropping conditions especially under wetter and cooler conditions. This is due to reduced grain yield under weed infestation, which increases the LER compared to no weed infestation. Bean partial LER decreased with increasing planting density while maize LER increased from low to medium density and reduced from medium to high density (Tsubo *et al.*, 2003). Total LER increased from low to medium density and decreased from medium to high density. Total LER less than 1 observed at both locations implies that maize and cowpea performed better under sole cropping than under intercropping conditions. Different growth duration cowpea cultivars produced similar amounts of N, thus no N differences were found in maize, cowpea and weed samples. The legume intercropping of different growth duration cowpea cultivars significantly affected the soil NO_3^--N but no differences were observed with NH_4^+-N. Soil nitrate and total N were significantly reduced by 47.7% and 38 %, respectively, due to weed infestation. The lack of significant differences for most maize growth and yield parameters might have been influenced by the lack of differences between cowpea N release.

5.2. Conclusions

1. Intercropping reduced maize LAI and plant height while time to physiological maturity was also reduced by weed infestation, especially under drier and warmer environments.
2. Glenda and Agrinawa intercrops produced more nodules per plant under cooler and wetter conditions. Agrinawa produced the highest leaf and total DMY under sole crop conditions and this was significantly reduced by weed infestation especially under warmer and drier conditions. Different growth duration cultivars did not differ in their N_2-binding abilities.
3. Maize intercropping, especially with Glenda and Agrinawa, significantly reduced weed biomass. This was because of high leaf and total DMY production, which probably inhibited weed growth.
4. Maize sole crop under zero weeds resulted in high yields compared to intercropping, especially under cooler and wetter conditions. PAN311 and Glenda sole crops under zero weeds produced higher yields under dry and warmer conditions, and cooler and wetter conditions compared to

intercropping. High yields were strongly correlated to more seeds per pod, increased pod lengths and number of pods per plant, especially for Glenda.

5. The reduction in cowpea and maize's growth and yield parameters under intercropping and weed infestation could have resulted from shading and competition for water and nutrients.
6. Total LER values less than 1 implies that maize and cowpeas must rather be planted as sole crops for better yields under wetter and cooler, and warmer and drier conditions.

5.3. Recommendations

1. Because of reduced maize and cowpea yield under intercropping compared to sole cropping, no intercropping should be practiced under cooler and wetter or warmer and drier conditions. Depending on the producers' objective and/or available land, intercropping can be practiced to produce more fodder yield, especially with Agrinawa.
2. Maize must rather be planted as sole crop, especially under cooler and wetter conditions because highest grain yields are obtained compared to warmer and drier conditions.
3. PAN311 and Glenda should be planted as sole crops under warmer and drier conditions, and wetter and cooler conditions, to ensure highest grain yield. Agrinawa should be planted as a sole crop in the absence of weeds for better total DMY, especially under warmer and drier conditions.
4. For future studies, there is a need to investigate the allelopathic activities of cowpeas on maize because of yield reduction under intercropping compared to sole cropping.
5. There is also a research need to quantify the BNF activity of different growth duration cowpea cultivars under crop rotations.

SUMMARY

Maize can be used in many forms including food for human consumption and livestock and for industrial purposes (Mouneke *et al*., 2007). The main purpose of intercropping is for the effective use of growth resources mainly because of the shortage of arable land (Willey, 1979 and O'Callaghan *et al*., 1994). Maize monocrop and intercropping with a long duration cultivar produced more LAI under cooler and wetter conditions while no differences were observed under warmer and drier conditions. Although no treatment effect was observed on total DMY and 50% flowering, maize at Bethlehem produced more total DMY than maize at Potchefstroom. Maize monocrop and intercropping with medium duration cowpea cultivars produced significantly taller maize plants under drier and warmer conditions. The number of days to physiological maturity was significantly reduced by cropping system treatment and weed infestation at both locations. Significant reduction of maize 100 seed mass by weed infestation was observed under cooler and wetter conditions and the same was also observed with ear and grain yield at both locations. Sole and intercropped maize with PAN311 produced the highest number of ears per plant under wetter and cooler conditions. More grain and ear yield was generally observed under maize sole cropping at both locations with higher yields under wetter and cooler conditions. Maize ear mass was the yield component, which strongly correlated to maize grain yield. The number of ears per plant at both locations and the 100 seed mass at Bethlehem also had a significant correlation with maize grain yield.

The number of cowpea nodules per plant increased with growth duration of the crops and this was also induced by intercropping conditions. Leaf and total DMY were also increased by growth duration of the crops at both locations and little weed infestation effect was observed with Glenda and Agrinawa intercrops at Potchefstroom. More leaf DMY and total DMY were produced under wetter and cooler conditions compared to warmer and drier conditions. Intercropping conditions significantly delayed cowpea number of days to 50% flowering and physiological maturity during both seasons at both locations. The medium and long duration cowpea cultivars produced more pods per plant under wetter and cooler conditions while the short duration cultivar produced more pods per plant under drier and warmer conditions. Number of pods per plant was significantly reduced by weed infestation under drier

and warmer conditions. The short duration cultivar as monocrop produced the greatest pod lengths at both locations during both seasons. More seeds per pod were produced by the short duration and medium duration cultivars at both locations. The medium duration cultivar intercrop was significantly reduced by weed infestation during the 2006/07 season under warmer and drier conditions. The short duration long duration cultivar produced more 100 seed mass especially under the drier and warmer conditions. The short duration cowpea cultivar produced more pod and grain yield under warmer and drier conditions while medium duration cultivars generally produced higher pod and grain yield under cooler and wetter conditions. Both pod and grain yield were reduced by weed infestation at both locations. Cowpea number of pods per plant, pod length and the number of seeds per pods were also correlated to grain yield.

Weed infestation was better controlled by cowpeas with longer growth duration, especially under intercropping with maize. This is because of the reduced weed dry matter yield under intercropping compared to sole cropping conditions, especially with the long duration cowpea cultivar. No intercropping advantage compared to sole cropping was observed, as the LER values were less than 1 during both seasons and locations. The presence of weeds under intercropping increased the LER values and this was more observed under cooler and wetter conditions. Non-significant differences were observed on plant nitrogen content for maize, cowpea and weed samples. Soil total N and NO_3^--N were significantly reduced by weed infestation while no differences were observed with soil NH_4^+-N between the treatments.

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APPENDIX A

Table 1 PR>F-values from the analysis of variance for maize leaf area index (LAI), total dry matter yield (DMY) (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of maize at Bethlehem and Potchefstroom during the 2005/06 and 2006/07 growing seasons.

Treatment Effect	LAI	Total DMY (kg ha^{-1})	Plant Height (cm)	Flowering (50%)	Physiological Maturity
		2005/06 Season			
Bethlehem					
Trt	0.0480	0.4407	0.5046	0.6542	0.0351
Weed	0.7890	0.9359	0.8520	0.4468	0.0029
Trt x Weed	0.6587	0.9829	0.9589	0.6103	0.0592
CV (%)	22.70	24.78		1.35	0.95
		2006/07 Season			
Trt	0.1321	0.0766	0.1885	0.4245	0.1416
Weed	0.4190	0.7210	0.9646	1.0000	0.0054
Trt x Weed	0.1015	0.7406	0.9466	0.5006	0.0849
CV (%)	12.63	13.57	9.68	2.08	0.75
Potchefstroom					
		2005/06 Season			
Trt	0.1732	0.1327	0.0936	0.8587	0.0127
Weed	0.2744	0.3943	0.0736	0.5796	0.0026
Trt x Weed	0.3800	0.8945	0.5475	0.2099	0.6133
CV (%)	21.06	18.35	3.18	0.99	1.22
		2006/07 Season			
Trt	0.6985	0.1014	0.0209	0.2303	0.0156
Weed	0.5007	0.6665	0.9298	0.7153	0.0142
Trt x Weed	0.8930	0.1721	0.5005	0.7381	0.2774
CV (%)	18.89	19.71	10.72	1.59	1.04

Trt = maize treatments (Four treatments consisting of maize mono and three intercrops with three cowpea cultivars); Weed = weed treatments (One with and one without weeds); Trt x Weed = maize-weed treatment interaction.

Table 2 Mean PR>F-values from the analysis of variance for maize leaf area index (LAI), total dry matter yield (DMY) (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of maize at Bethlehem and Potchefstroom for two seasons

Treatment effect	LAI	Total DMY (kg ha^{-1})	Plant Height (cm)	Flowering (50%)	Physiological Maturity
			Bethlehem		
Trt	0.0980	0.1833	0.3755	0.5518	0.0331
Weed	0.9552	0.8279	0.9774	0.7508	0.0025
Trt x Weed	0.5659	0.9714	0.9560	0.5227	0.0512
CV	15.41	14.33	4.05	1.64	0.79
			Potchefstroom		
Trt	0.2818	0.0956	0.0279	0.2707	0.0042
Weed	0.4404	0.2378	0.5509	0.7475	0.0032
Trt x Weed	0.5355	0.3043	0.5504	0.4131	0.4124
CV	15.58	10.22	6.18	0.88	1.02

Trt = maize treatments (Four treatments consisting of maize mono and three intercrops with three cowpea cultivars); Weed = weed treatments (One with and one without weeds); Trt x Weed = maize-weed treatment interaction.

Table 3 PR>F-values from the analysis of variance for cowpea nodule number per plant, leaf dry matter (DM) yield (kg ha^{-1}), total DM yield (kg ha^{-1}), days to 50% flowering and physiological maturity at Bethlehem and Potchefstroom during the 2005/06 and 2006/07 growing seasons.

Treatment Effect	Nodule Number	Leaf DMY (kg ha^{-1})	Total DMY (kg ha^{-1})	Flowering (50%)	Physiological Maturity
Bethlehem					
		2005/06 Season			
Trt	0.0033	0.0001	0.0000	0.0000	0.0000
Weed	0.2189	0.3863	0.4826	0.9336	0.0004
Trt x Weed	0.5309	0.8771	0.5658	0.0000	0.0000
CV (%)	40.36	30.50	22.25	2.54	0.79
		2006/07 Season			
Trt	0.0060	0.0000	0.0000	0.0000	0.0000
Weed	0.9341	0.0252	0.1301	0.0959	0.0067
Trt x Weed	0.5363	0.0000	0.0062	0.0000	0.0000
CV (%)	35.93	22.98	22.42	4.13	1.41
Potchefstroom					
		2005/06 Season			
Trt	0.0247	0.0000	0.0000	0.0000	0.0000
Weed	0.2170	0.0048	0.4080	0.0000	0.0001
Trt x Weed	0.1080	0.0000	0.0015	0.0058	0.0003
CV (%)	48.67	15.93	10.85	3.20	1.83
		2006/07 Season			
Trt	0.0113	0.0000	0.0010	0.0000	0.0000
Weed	0.0469	0.0012	0.0062	0.0000	0.0000
Trt x Weed	0.1205	0.0000	0.0024	0.0000	0.0000
CV (%)	45.42	17.21	22.77	1.10	0.81

Trt = Cowpea treatments (Six treatments consisting of three mono and three intercrops); Weed = weed treatments (One with and one without weeds); Trt x Weed = cowpea-weed treatment interaction.

Table 4 PR>F-values from the analysis of variance for cowpea nodule number per plant, leaf dry matter (DM) yield (kg ha^{-1}), total DM yield (kg ha^{-1}), days to 50% flowering and physiological maturity at Bethlehem and Potchefstroom for two seasons' average.

Treatment effect	Nodule number	Leaf DMY (kg ha^{-1})	Total DMY (kg ha^{-1})	Flowering (50%)	Physiological maturity
			Bethlehem		
Trt	0.0014	0.0000	0.0000	0.0000	0.0000
Weed	0.4990	0.9448	0.7737	0.2343	0.0009
Trt x Weed	0.6390	0.0378	0.0142	0.0000	0.0000
CV	27.48	19.85	13.40	3.05	0.97
			Potchefstroom		
Trt	0.0016	0.0000	0.0000	0.0000	0.0000
Weed	0.6811	0.0000	0.0042	0.0000	0.0000
Trt x Weed	0.0683	0.0000	0.0001	0.0013	0.0000
CV	36.72	9.89	10.21	1.77	1.09

Trt = Cowpea treatments (Six treatments consisting of three mono and three intercrops); Weed = weed treatments (One with and one without weeds); Trt x Weed = cowpea-weed treatment interaction.

Table 5 PR>F-values from the analysis of variance for weed dry matter yield (kg ha^{-1}) at Bethlehem and Potchefstroom during 2005/06 and 2006/07 growing seasons and their means.

Treatment	**Bethlehem**	**Potchefstroom**
	2005/06 season	
Treatment	0.1685	0.0046
CV (%)	50.66	43.98
	2006/07 season	
Treatment	0.0006	0.0131
CV (%)	26.12	35.17
	Mean	
Treatment	0.0566	0.0001
CV (%)	36.35	22.26

Treatment = Weed dry matter

APPENDIX B

Table 1 PR>F-values from the analysis of variance for maize ear number per plant, ear length (cm), seed per ear, 100 seed mass (g), ear mass (kg ha^{-1}) and grain yield (kg ha^{-1}) at Bethlehem and Potchefstroom during the 2005/06 and 2006/07 growing seasons.

Treatment Effect	Ear number $plant^{-1}$	Ear length (cm)	Seed per cob	100 seed mass (g)	Ear mass (kg ha^{-1})	Grain yield (kg ha^{-1})
Bethlehem						
2005/06 growth season						
Trt	0.5083	0.2402	0.5028	0.0933	0.0229	0.0327
Weed	0.1051	0.3838	0.3169	0.0344	0.1285	0.1300
Trt x Weed	0.8245	0.9893	0.9996	0.6251	0.9325	0.8495
CV (%)	26.67	9.78	12.31	5.84	24.86	22.99
2006/07 growth season						
Trt	0.0226	0.3483	0.9477	0.4933	0.0789	0.0998
Weed	0.0817	0.0505	0.0646	0.0009	0.0020	0.0030
Trt x Weed	0.4439	0.6765	0.5440	0.4488	0.2809	0.4330
CV (%)	18.95	11.06	29.70	5.36	27.52	30.80
Potchefstroom						
2005/06 growth season						
Trt	0.1297	0.9870	0.1880	0.2181	0.0212	0.0271
Weed	0.5333	0.2388	0.6694	0.4967	0.0322	0.0230
Trt x Weed	0.7071	0.2570	0.4490	0.1958	0.5648	0.5408
CV (%)	13.32	9.37	13.39	3.81	9.74	10.02
2006/07 growth season						
Trt	0.3692	0.5451	0.6803	0.4463	0.0028	0.0048
Weed	0.1562	0.0477	0.3896	0.5964	0.5151	0.9298
Trt x Weed	0.7753	0.2111	0.7011	0.6646	0.0526	0.1159
CV (%)	40.94	11.92	36.66	9.81	21.66	25.52

Trt = maize treatments (Four treatments consisting of maize mono and three intercrops with three cowpea cultivars); Weed = weed treatments (One with and one without weeds); Trt x Weed = maize-weed treatment interaction.

Table 2 PR>F-values from the analysis of variance for maize ear number per plant, ear length (cm), seed per ear, 100 seed mass (g), ear mass (kg ha^{-1}) and grain yield (kg ha^{-1}) at Bethlehem and Potchefstroom for two seasons' averages.

Treatment Effect	Ear number per Plant	Ear length (cm)	Seed per cob	100 seed mass (g)	Ear mass (kg ha^{-1})	Grain Yield (kg ha^{-1})
Bethlehem						
Trt	0.1846	0.8496	0.6048	0.2888	0.0369	0.0380
Weed	0.0379	0.0635	0.0105	0.0047	0.0012	0.0013
Trt x Weed	0.7879	0.9239	0.3996	0.5593	0.4114	0.4846
CV (%)	17.57	7.58	9.50	5.39	15.40	15.37
Potchefstroom						
Trt	0.1309	0.7755	0.3827	0.4255	0.0036	0.0056
Weed	0.0692	0.0049	0.2884	0.3533	0.1188	0.0376
Trt x Weed	0.4328	0.0095	0.1975	0.1655	0.2219	0.2724
CV (%)	11.32	4.98	11.82	3.92	7.84	8.62

Trt = maize treatments (Four treatments consisting of maize mono and three intercrops with three cowpea cultivars); Weed = weed treatments (One with and one without weeds); Trt x Weed = maize-weed treatment interaction.

Table 3 PR>F-values from the analysis of variance for cowpea pod number per plant, pod length, seed per pod, 100 seed mass (g), pod mass (kg ha^{-1}) and grain yield (kg ha^{-1}) at Bethlehem and Potchefstroom during the 2005/06 and 2006/07 growing seasons.

Treatment Effect	Pod number per Plant	Pod length (cm)	Seed per pod	100 seed mass (g)	Pod mass (kg ha^{-1})	Grain yield (kg ha^{-1})
Bethlehem						
2005/06 growth season						
Trt	0.0000	0.0031	0.0002	0.0000	0.0000	0.0000
Weed	0.6722	0.2837	0.5618	0.0000	0.0222	0.0040
Trt x Weed	0.4297	0.4445	0.1120	0.0000	0.0211	0.0003
CV (%)	39.82	11.21	15.15	2.55	28.25	32.85
2006/07 growth season						
Trt	0.1472	0.0786	0.0000	0.0000	0.0000	0.0001
Weed	0.0236	0.7089	0.4500	0.2699	0.0064	0.0356
Trt x Weed	0.0625	0.9077	0.6165	0.3168	0.0060	0.0256
CV (%)	31.14	7.53	9.17	6.89	28.38	31.14
Potchefstroom						
2005/06 growth season						
Trt	0.0000	0.0000	0.0000	0.0235	0.0000	0.0000
Weed	0.0000	0.7052	0.6391	0.3922	0.0057	0.0054
Trt x Weed	0.0064	0.5417	0.4159	0.7071	0.1755	0.5454
CV (%)	13.84	23.03	23.03	9.51	33.90	30.27
2006/07 growth season						
Trt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Weed	0.0441	0.1696	0.1376	0.0346	0.0155	0.0146
Trt x Weed	0.2237	0.0069	0.0316	0.0416	0.0333	0.1976
CV (%)	47.07	5.50	9.54	5.56	16.85	24.58

Trt = 6 cowpea treatments (3 mono and 3 intercrops); Weed = weed treatments (1 with and 1 without weeds); Trt x Weed = cowpea-weed treatment interaction.

Table 4 PR>F-values from the analysis of variance for cowpea pod number per plant, pod length, seed per pod, 100 seed mass (g), pod mass (kg ha^{-1}) and grain yield (kg ha^{-1}) at Bethlehem and Potchefstroom for two seasons' average.

Treatment Effect	Pod Number per Plant	Pod length (cm)	Seed per pod	100 seed mass (g)	Pod mass (kg ha^{-1})	Grain Yield (kg ha^{-1})
			Bethlehem			
Trt	0.0003	0.0024	0.0000	0.0050	0.0000	0.0000
Weed	0.3140	0.2978	0.7573	0.3099	0.0016	0.0016
Trt x Weed	0.2926	0.7216	0.3744	0.0175	0.0015	0.0006
CV (%)	33.95	6.68	10.04	4.04	20.99	22.39
			Potchefstroom			
Trt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Weed	0.0016	0.9400	0.3054	0.0426	0.0054	0.0046
Trt x Weed	0.1302	0.4894	0.1486	0.1351	0.3329	0.4170
CV (%)	24.10	10.76	12.54	4.83	26.65	25.85

Trt = 6 cowpea treatments (3 mono and 3 intercrops); Weed = weed treatments (1 with and 1 without weeds); Trt x Weed = cowpea-weed treatment interaction.

Table 5 PR>F-values from the analysis of variance for soil NH_4, NO_3 and total N (NH_4+NO_3) at Potchefstroom during the 2006/07 season.

Treatment effect	NH_4	NO_3	Total N (NH_4+NO_3)
Trt	0.6368	0.3030	0.2490
Weed	0.1207	0.0001	0.0003
Trt x Weed	0.7892	0.7800	0.7958
CV	25.58	36.61	31.41

Trt = main maize treatments (4 treatments consisting of maize mono and 3 intercrops with three cowpea cultivars) and cowpea treatments (6 cowpea treatments consisting of 3 mono and 3 intercrops) ; Weed = 2 levels of weed infestation (One with and one without weeds); Trt X Weed = main maize/cowpea treatment and weed interaction.

Table 6 PR>F-values from the analysis of variance for maize, cowpea and weed plant N (%) at Potchefstroom during the 2006/07 season.

Treatment effect	Maize Trt	Cowpea Trt	Weed Trt
Plant N (%)	0.0756	0.0632	0.9217
CV	12.35	6.79	16.70

Maize Trt = 4 maize treatments at no weed infestation (1 mono and 3 intercrops with cowpeas); Cowpea Trt = 6 cowpea treatment at no weed infestation (3 cultivars each sole and intercropped); Weed Trt = *Amarunthus* weed samples from 7 weeded plots.