PRODUCTIVITY OF FIVE PIGEONPEA (*Cajanus cajan*) VARIETIES IN PIGEONPEA-MAIZE STRIP INTERCROPPING IN LIMPOPO PROVINCE

by

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DECLARATION

I, Madimabe Koketso Sherleen, declare that the thesis I hereby submit for the degree MSc (Agronomy) at the University of Limpopo, Department of Plant Production, Soil Science and Agricultural Engineering, is my own work and has not been previously submitted by me for the degree purpose at another university or Institution of Higher Education. I also certify that no plagiarism was committed when writing this dissertation.

Madimabe K.S. (Ms)	Date

DEDICATION

This work is dedicated to my late beloved mother, Madimabe Tlou Dalsy, and my loving and supportive family who have always stood by me and kept me in their thoughts and prayers throughout my endeavours.

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ABSTRACT

Pigeonpea (*Cajanus cajan* (L) Millsp.) is an important grain legume crop in tropical and subtropical countries, where it provides a cheap source of protein. Smallholder farmers in Limpopo Province cultivate landraces of pigeonpea, which are characterised with late maturity, low grain yield and being sensitive to photoperiod. To increase the productivity of the cropping system involving pigeonpea, several early-medium maturity varieties have been introduced. However, performance of the varieties has not been tested in strip intercropping in Limpopo Province. Farmers plant these landraces by using mixed intercropping without definite row arrangement. This practice does not optimise plant density; it hinders farm inputs application and is characterised producing low yields. Therefore, the inclusion of early maturing varieties of pigeonpea in an intercrop will enable farmers to select the best variety for planting in future and thus enhance their output as well as their productivity. The objectives of this study were to assess the agronomic performance of five pigeonpea varieties in pigeonpea-maize strip intercropping, to determine the effect of strip intercropping on maize yield and establish the effect of location and season variations on the performance of both component crops under the intercropping system.

Experiments were conducted at the University of Limpopo Experimental Farm (UL Farm) and Ga-Thaba village during the 2015/16 and 2016/17 season. Five improved early-medium maturing pigeonpea varieties (ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2) from ICRISAT were evaluated under strip intercropping with maize cultivar PAN 6479. The varieties were selected as early-medium maturing varieties from previous pigeonpea trials. The trials were laid in a split plot design. The main plot comprised cropping systems (intercrop and monocrop), while the subplot comprised the varieties with three replications. Data collected on pigeonpea were number of days to 50% flowering and 90% maturity number of primary branches; plant height (cm); number of pods per plant; pod length (cm); number of seed per pod; hundred seed weight (g); and grain yield (kg ha^{-1}), whereas on maize, number of days to 50% tasselling and silking; plant height (cm); cob length (cm); cob per plant; grain yields (kg ha^{-1}); and stover (kg ha^{-1}) were recorded. LER was calculated to determine intercropping productivity. Data analysis was done using Statistic 10.0; and Least Significance Difference (LSD) was used to separate the means that showed significant differences at an alpha level of 0.05. The results revealed significant differences in nearly all pigeonpea variables expect (pod length, number of seed per pod and hundred seed weight). Variables that showed significant differences in maize were plant height, cob length, grain yields and stover.

Number of days to 50% flowering and 90% physiological maturity differed significantly ($P \leq 0.05$) among varieties at the UL Farm and Ga-Thaba. Varieties (ICEAP 001284 and ICEAP 00604) exhibited the shortest number of days to 50% flowering and 90% maturity in both locations during both seasons. The interaction between variety x season (V x S) showed significant ($P \leq 0.05$) differences in pigeonpea grain yield. The top yielders during 2015/16 at the UL Farm were ICEAP 01101-2 (1555 kg ha^{-1}) and ICEAP 001284 (1280 kg ha^{-1}), while during the 2016/17 season, they were ICEAP 001284 (937 kg ha^{-1}) and ICEAP 01101-2 (912 kg ha^{-1}). High yielder at Ga-Thaba during the 2016/17 season were ICEAP 001284 and ICEAP 01101-2 with grain yields of 671 kg ha^{-1} and 627 kg ha^{-1}, respectively. Furthermore, varieties that obtained high yields during the 2015/16 season were ICEAP 001284 (504 kg ha^{-1}) and ICEAP 00604 (541 kg ha^{-1}). Most of the varieties during both seasons at the UL Farm and Ga-Thaba yielded more than 500 kg ha^{-1} under strip intercropping as compared to mixed intercropping, which obtained yields averages of below 400 kg ha^{-1}. The highest maize grain yields of 1450 kg ha^{-1} were recorded during 2015/16 as compared to 958 kg ha^{-1} during the 2016/17 season at the UL Farm. The calculated total Land Equivalent Ratio (LER) for the two crops in both locations gave positive and higher than 1 values, which suggests a favourable grain yield advantage for maize-pigeonpea strip intercrop over mixed intercropping.

Key words: *Cajanus cajan*, maize, cropping system, maturity, grain yields, land equivalent ratio

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CHAPTER 1

INTRODUCTION

1.1 Background

Pigeonpea (*Cajanus cajan*) is one of the most important grain legume crops grown in the tropics and subtropics. It is believed to have originated from India (Saxena *et al.,* 2002). It is a multipurpose drought-tolerant crop producing seeds for human consumption as a source of protein, and provides good quality fodder for animal feed (Gwata and Siambi, 2009). Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat and about 1% embryo, and contain a variety of dietary nutrients (Singh *et al.,* 1984; Ezeaku *et al.,* 2016). The cotyledons are rich in carbohydrates (66.7%), while a major proportion (about 50%) of seed protein is in embryo stage seed (Sarode *et al.,* 2009). It is highly nutritious and may contain 18-25% protein, 51-58% carbohydrate, and important minerals and vitamins (Odeny, 2007). Besides pigeonpea's nutritional value, it also acts as a soil fertility improvement through biological nitrogen fixation (BNF). Pigeonpea can fix up to 235 kg N ha-1 (Peoples *et al.*, 1995; Egbe, 2007; Njira *et al.,* 2012) and produces more N per unit area from plant biomass than many other legumes (Njira *et al.,* 2012). Legume intercrops are a source of plant N through atmospheric fixation that can offer a practical complement to inorganic fertilisers (Jerenyama *et al.,* 2000) and reduce competition for N from cereals' component (Allen and Obura, 1983). Pigeonpea is cultivated as an important companion crop because it fixes nitrogen and uses its deep root system to bring up minerals from horizons inaccessible by other crops (Kumar *et al.,* 2011). Due to this, pigeonpea is mainly cultivated in intercropping systems with maize, leading to the reduced need for commercial nitrogen fertilisers (Adu-Gyamfi *et al.,* 2007).

Maize (*Zea mays L*.) is the third most important cereal crop in the world after wheat and rice. Maize grain is used for many purposes; for example, as a staple food for human beings; feed for livestock; and as a raw material for many industrial products (Drinkwater *et al.,* 2009). However, maize yields in the Limpopo Province are in decline due to continuous maize interplanting with legumes without any definite row arrangement, and risks from erratic and low rainfall (Makgoga, 2013). Therefore, inclusion of pigeonpea into a cropping system will provide some assurance against crop failure. The crop also has the potential to improve livelihoods of farm households through increased protein in the diet.

Intercropping of legumes with cereals is an ancient practice and is important for the development of sustainable food production systems, particularly among smallholder (SH) farmers in South Africa (Thobatsi, 2009). Cereal/legume intercropping is commonly practised in South Africa, including the Limpopo Province, because of yield advantage, greater stability and lower risks of crop failure that are often associated with monoculture (Sullivan, 2003). According to Nndwambi (2015), different authors have reported cereal/legume intercrop trials in South Africa. These include maize and pigeonpea (Mathews *et al.,* 2001), and maize and dry bean intercropping (Kutu and Asiwe, 2010). In the Limpopo Province, mixed interplanting is a common intercropping practice, whereby legumes are planted together with cereals without any definite row arrangement. This practice does not optimise plant density nor does it allow efficient management of crops by using modernised equipment. It hinders application of farm inputs and it is characterised by low yields (Asiwe *et al.,* 2011). Strip intercropping is growing two or more crops together in strips wide enough to permit separate management of crops, but close enough for the crops to interact (Singh and Ajeigbe, 2007). Strip intercropping great potential of reducing inter-species competition, allowing individual management of intercrops and optimising plant density, thereby increasing yields per unit area. However, performance of improved early-medium pigeonpea varieties from ICRISAT has not been studied in detail under a strip intercropping system with maize in the Limpopo Province.

1.2 Problem Statement

Pigeonpea is a drought-tolerant crop (Kumar *et al.,* 2011), which makes it a relevant crop in dry areas such as the Limpopo Province. In South Africa, especially in the Limpopo Province, mixed interplanting is a common intercropping practice, whereby legumes are planted together with cereals without any definite row arrangement. As already stated, this practice does not optimise plant density nor does it allow efficient management of crops by using modernised equipment. It hinders farm inputs application and it is characterised by low yields (Asiwe *et al.,* 2011). As previously explained, strip intercropping refers to the growing of two or more crops together in strips wide enough to permit separate management of crops, but close enough for the crops to interact (Singh and Ajeigbe, 2007). This practice has great potential of reducing inter-species competition and to increase yields per unit area. However, little or no research has been conducted to evaluate the performance of pigeonpea in a strip intercropping system with maize in the Limpopo Province. There is therefore, a need to conduct research on a pigeonpea-maize strip intercropping system in the Limpopo Province.

1.3 Hypothesis

The performance of pigeonpea and maize in pigeonpea-maize strip intercropping does not differ from sole/single crops and mixed intercropping.

1.4 Motivation for the study

Pigeonpea is an important grain legume crop in tropical and subtropical countries, where it provides a cheap source of protein (Gwata and Siambi, 2009). In India, pigeonpea is cultivated as an important companion crop because it fixes nitrogen and uses its deep root system to bring up minerals from horizons inaccessible by other crops. Smallholder farmers are the most important food security stakeholders in the Limpopo Province. According to ICRISAT (2008), smallholder farming areas of the Limpopo Province are subjected to frequent drought and poor soil fertility, thus limiting crop production. Therefore, strip intercropping of pigeonpea with maize will be an alternative system for smallholder farmers to improve food production per unit area. South Africa, particularly the Limpopo Province, is a semi-arid region, characterised by marginal soil, low erratic rainfall or uneven rainfall distribution and this results in reduced crop yields (Mpandeli *et al*., 2015). Therefore, introducing improved early maturing varieties of pigeonpea, which are drought tolerant in an intercropping manner to smallholder farmers will increase their productivity. However, performance of pigeonpea under a strip intercropping system with maize has not been studied in the Limpopo Province. Therefore, this study will generate information that will update the cropping system database in the Limpopo Province and add further knowledge to the research body.

1.5 Purpose of the Study

1.5.1 Aim

The aim of this study was to establish how to improve maize and pigeonpea yield through strip intercropping.

1.5.2 Objectives

1. To assess the agronomic performance of five pigeonpea varieties in pigeonpea-maize strip intercropping.
2. To determine the effect of strip intercropping on maize yield.
3. To establish the effect of location and season variations on the performance of both component crop under an intercropping system.

CHAPTER 2

LITERATURE REVIEW

2.1 General Information on Pigeonpea

Pigeonpea (*Cajanus cajan* L. Millsp), also known as red gram, Congo pea, gungo pea and no-eye pea, occurs in several varieties (Saxena *et al*., 2002). It is a drought-tolerant crop and one of the most important legumes grown in the tropics and subtropics (Gwata and Siambi, 2009). As a rich source of protein for humans (Saxena *et al*., 2002), pigeonpea is mostly used in diets to supplement cereals that are protein deficient (Saxena *et al*., 2002). Hundred seed grams (100 grams) of dry seeds contain 343 calories, and 21.70 g or 39% of the recommended daily values of protein (Saxena *et al*., 2002). Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat and about 1% embryo, and contain a variety of dietary nutrients (Singh *et al.,* 1984; Ezeaku *et al.,* 2016). Pigeonpea seeds have good amounts of dietary fibre, providing 15 g or 39% of fibre per 100 grams. Pigeonpea is highly nutritious and may contain 18-25% protein, 51-58% carbohydrates, and important minerals and vitamins (Odeny, 2007). Furthermore, its high nutritional value has also made pigeonpea a reliable source for fodder (Saxena *et al.,* 2002).

The plant is a short-lived perennial shrub; it grows to two to four metres in height, and its flowers are yellow or yellow and red (Valenzuela and Smith, 2002). Pigeonpea leaves consist of three leaflets and are dark green above and silvery underneath (Saxena *et al.,* 2010a). The pods are usually 5 to 9 cm long and 12 to 13 mm wide, containing four to five seeds (Valenzuela and Smith, 2002). The seeds can be a range of colours, some are light brown, but they can be cream, grey, purple or black, depending on the variety (Saxena *et al.,* 2010a). Pigeonpea is a drought-tolerant crop with large variation for days to maturity, ranging from extra short (90 days) duration to long duration (300 days) (Saxena *et al.,* 2010a). Being a drought-tolerant crop makes it well adapted in areas, where rainfall is low or erratic and other crops do not perform well (Gwata and Siambi, 2009).

2.2 Importance of Pigeonpea

Globally, pigeonpea is the fifth most important pulse crop, mainly grown in the developing countries (Saxena *et al.,* 2010b). It is considered as one of the most nutritious legumes with high levels of amino acids and is mainly used to supplement food that contains high levels of carbohydrate such as maize, cassava and rice (Saxena *et al.,* 2010b). Because of the high protein levels (18-25% protein, 51-58% carbohydrate, and important minerals and vitamins) in the grain (Odeny, 2007), the legumes are a valuable source of affordable protein, particularly in rural smallholder communities that largely depend on cereal-based diets and a face high risk of malnutrition (Gwata, 2010). Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat, and about 1% embryo, and contain a variety of dietary nutrients (Ezeaku *et al.,* 2016). The cotyledons are rich in carbohydrates (66.7%), while a major proportion (about 50%) of seed protein is in embryo (Sarode *et al.,* 2009). Dry pigeonpea leaves are used as fodder for livestock feeding (Mathews and Saxena, 2000). It can also be used as a shadow crop, windbreak, cover crop and green manure for vegetables, and even as a traditional medicine (Kooner and Cheema, 2010). The dry branches and stem serve as firewood and roofing (Mula and Saxena, 2010).

Like most members of the fabaceae family (cowpea, soybean and groundnut), pigeonpea has root nodules and helps improve soil quality through biological nitrogen fixation (Rao and Mathuva, 2000; Abunyewa and Karbo, 2005). Therefore, pigeonpea is mainly cultivated in intercropping systems with maize, leading to the reduced need for commercial nitrogen fertilizers (Adu-Gyamfi *et al.,* 2007). Makelo (2011) stated that pigeonpea is also capable of bringing minerals from deeper soil horizons to the soil surface and improving soil aeration. Pigeonpea has also been found to be very useful in intercropping with cereal crops such as maize as it can replenish nitrogen in the soil, being rich in nutrients, which helps to enrich the soil for an increased productivity. This is particularly important for smallholder farmers who are subjected to erratic rainfall and poor soil fertility (Nndwambi, 2015). Pigeonpea can fix up to 235 kg N ha-1 (Peoples *et al.*, 1995; Egbe, 2007; Njira *et al.,* 2012) and produces more N per unit area from plant biomass than many other legumes (Njira *et al.,* 2012). Cereal-legume intercropping is beneficial as legumes supply most of the nitrogen in the soil. Thus, atmospheric nitrogen (N) fixation is achieved through a symbiotic relationship between legume and specific rhizobium, thereby increasing soil nitrogen available for the companion crop (Bambalele, 2016). Legume species commonly used for provision of grain and green manure have the potential to fix between 100 and 300 kg N ha-1 from the atmosphere (Jerenyama *et al.,* 2000).

2.3 Pigeonpea Types

There are many varieties of pigeonpea around the world, from a tall tree-like species to smaller bushes and dwarf varieties (Saxena *et al.,* 2010a). The different varieties also mature at different times (Saxena *et al.,* 2010a). Maturity duration is a very important factor that determines the adaptation of varieties to different agro-climatic areas and cropping systems (Mathews and Saxena, 2000).

Most smallholder farmers in South Africa grow local landraces of pigeonpea (Kooner and Cheema, 2010). The landraces are characterised by late maturity, inherently low grain yield and dark seeds (Gwata and Shimelis, 2013). Landraces of pigeonpea have been associated with low yields in countries where they are grown (Khaki, 2014). The average yields of pigeonpea landraces are as low as 250 to 450 kg/ha and some take time to mature (Khaki, 2014). The improved cultivars are introduced through breeding and fall into either short-duration (SD), medium-duration (MD) or long-duration (LD) types (Gwata and Shimelis, 2013). This classification is based on the duration to maturity (Mligo and Craufurd, 2005). The short-duration types require about 120 days to mature (Mligo and Craufurd, 2005). Therefore, they mature before the onset of drought conditions, and these variety types are suitable for places that experience erratic or low rainfall such as the Limpopo Province. Adaptation of pigeonpea to semi-arid and arid regions and poor soils makes it a suitable crop to provide income and ensure food security in these regions, which are less suitable for many other crops (Khoury *et al.,* 2015). Short-duration pigeonpea varieties usually escape drought and are less sensitive to photoperiod than traditional varieties with longer growth cycles (Silim *et al.,* 2007). Medium-duration (MD) types require about 180 days to attain maturity, while long-duration (LD) types can require up to 240 days to mature fully and are sensitive to photoperiod (Gwata and Shimelis, 2013).

2.4 World Pigeonpea Production Statistics

Pulses are of greatest importance in the human diet (Sarika *et al.,* 2013). Pigeonpea is one of the most protein-rich legumes of the semi-arid tropics grown throughout the tropical and subtropical regions of the world (Sarika *et al.,* 2013). After chickpea, pigeonpea is the second most important pulse crop of India and it is well balanced nutritionally (Khaki, 2014). India is one of the major pigeonpea producing countries with 63.74 % of total global production, followed by Myanmar (18.98%), Malawi

(6.07%), Tanzania (4.42%) and Uganda (1.98%) (Hardev, 2016). In India, pigeonpea occupies an area of 3.81 million hectares, with production and productivity of 3.07 million tons and 806 kg\ha, respectively (Hardev, 2016).

According to Odeny cited by Nndwambi (2015), production in African countries contributes 9.3% of world production, which is very little compared to the 74% contribution from India alone. In South Africa, pigeonpea is not widely grown as a field crop, but is mainly planted in home gardens, particularly in the Limpopo, Mpumalanga and KwaZulu-Natal provinces (Nndwambi, 2015; Hluyako, 2015). However, pigeonpea can also serve as an important grain legume crop for human consumption that can be used in rural areas and supplement the range of food crops available (Gwata and Siambi, 2009). Production areas in Limpopo are Bohlabela and Mopani districts, while in Mpumalanga, pigeonpea is grown in the Gert Sibande, Enkangala and Ehlanzeni districts (Department of Agriculture, 2010).

2.5 Background of Maize

Maize (*Zea mays* L.), also called corn, belongs to the family gramineae (grass family) and originated from Mexico, but its production spread quickly around the world (Kgonyane *et al.,* 2013). It is the third most important cereal crop after wheat *(Triticum aestivum L.*) and rice *(Oryza sativa*) in the world and is used as staple food for human beings, feed for livestock and poultry, forage for mich and draft animals (Thobatsi, 2009). Maize is the most important grain crop in South Africa, being both the major feed grain and the staple food of the majority of the South African population (Medupe, 2010). Maize contains about 72% starch, and 10% protein (Kgonyane *et al.,* 2013).

2.6 Maize Production in South Africa

Maize is a dominant crop in smallholder farming systems in South Africa and it is produced throughout the country under the diverse environments (Kgonyane *et al.,* 2013). Generally, it is cultivated as monocrop or intercrop with grain legumes such as cowpea, groundnut, bambara groundnut and pigeonpea (Thobatsi, 2009). Despite the drought and erratic rainfall in South Africa, maize still is grown throughout the year, although there are significant differences in yields (Medupe, 2010). Area under maize varied from year to year, depending on the weather and market conditions, but an average of approximately 10-12 million tons of maize on 2.5-2.75 million hectares of land are produced in South Africa annually (Syngenta, 2012). About 59% of maize produced in South Africa is white and the remaining 41% is yellow maize (DAFF, 2017). White maize is primarily used for human consumption, while yellow maize is mostly used for animal feed production (Department of Agriculture, 2010). According to the report of DAFF (2017), the two main provinces in South Africa, where white maize is grown, are the Free State and North West provinces, produced about 78% of the white maize; and the Free State and Mpumalanga provinces produced about 67% of the yellow maize. The Free State (44%), North West (19%), Mpumalanga (20%), Gauteng (5%) KwaZulu-Natal (4%), Northern Cape (4%), Limpopo (3%), Eastern Cape (1%) and Western Cape (0%) recorded production of maize in South Africa during the 2016/17 production season of the national total (DAFF, 2017).

2.7 Cropping Systems

Cropping systems are defined as the pattern of crops taken up for a given piece of land, or sequence in which the crops are cultivated on a piece of land over a fixed period, and their interaction with farm resources and other farm enterprises (Medupe, 2010). The forms of cropping systems that are practised throughout the world are the results of variation in local climate, as well as availability of moisture and nutrients in the soil (Medupe, 2010; Makgoga, 2013). Monocropping, intercropping and mixed intercropping of legumes and cereals are dominant cropping systems that are practised by smallholder farmers in South Africa (Medupe, 2010).

2.7.1 Monocropping

Monocropping or single cropping refers to growing only one crop on a land year after year or the practice of growing only one crop on a piece of land annually (Medupe, 2010). Due to limited land availability in the Limpopo Province (Ayisi and Mpangane, 2004), smallholder farmers are forced to practise intercropping. Examples of annual crops that are currently cultivated by smallholder farmers in the Limpopo Province annually are maize and grain legumes; however, grain legumes are grown on very small portions of the land on smallholder farms. Cultivating a single crop annually can lead to total crop failure, especially in the area associated with erratic seasonal rainfall distribution such as Limpopo Province (Makgoga, 2013). Elliot *et al*., cited by Makgoga (2013), reported that the practice of monoculture in dry areas could result in reduced yields, particularly when a field is cropped annually; therefore, the inclusion of legumes in the cropping system through strip intercropping will reduce the risk of total crop failure.

Reduced soil fertility has been reported as one of the major factors causing a decline in food production (Thobatsi, 2009), and it has been caused by the continuous cultivation of cereals through monocropping. Medupe (2010) also reported that in areas where monocropping is practised mainly by the smallholder farmers, soil fertility and crop yields decline rapidly, if nutrients are not supplemented. Therefore, cultivation of a leguminous crop like pigeonpea in the cropping systems through strip intercropping does not only improve the nutrient status of the soil, but also improves and sustains agricultural productivity.

Monocropping is characterised by high competition for growth factors such as water and nutrients (Thobatsi, 2009). Nzabi *et al*., cited by Makgoga (2013), reported that deep rooting legumes, such as pigeonpea, also take up nutrients from deeper soil layers and reduce the competition for nutrients uptake with cereals, thus enhancing absorption of nutrients by cereals in the top layers. Medupe (2010) further reported that cereal/legume intercropping uses water more efficiently than monoculture does through reduced soil surface evaporation, which results in less water competition and is important under unfavourable water conditions. Advantages of practising monocropping are low labour requirements as compared to intercropping because in sole cropping it is easier to plant and harvest single crops (Makgoga, 2013).

2.7.2 Mixed intercropping

Mixed intercropping is the cultivation of two or more crops simultaneously on the same field without a row arrangement (Singh and Ajeigbe, 2007). Due to limited land availability in the Limpopo Province (Ayisi and Mpangane, 2004), smallholder farmers are forced to practise mixed intercropping. Examples of mixed intercropping of the annual crops that are practised by smallholder farmers in the Limpopo Province are maize, cowpea, watermelon, groundnuts and squash, where farmers broadcast seeds without row arrangement. This practice does not optimise plant density, and it causes problems in performing all the agricultural operations and harvesting of the crops, as well as a reduction in yield of the component crops, which may occur due to intense competition for growth factors such as light, water and nutrients.

Sullivan (2003) reported labour requirements in the mixed interplanting system are higher than in sole cropping, as multiple crops are planted at the same time or shortly after one another and harvested at various times. Therefore, introduction of a new technique such as strip intercropping to smallholder farmers is an advantageous alternative as compared to other intercropping arrangements since it allows efficient management of crops using modernised equipment (Sullivan, 2003). However, Bambalele (2016) reported that mixed intercropping is characterised by low yield because legumes are planted together with cereals without any definite row arrangement and this results in high competition for growth factors such as nutrients, light and water.

2.7.3 Intercropping

Intercropping is the practice of growing two or more crops simultaneously in the same field at the same time (Sullivan, 2003). Cereal-legume intercropping is the most common intercropping system, which has been practised by smallholder farmers for decades (Dania *et al.,* 2014). In Mozambique, smallholder farmers usually intercrop maize with cowpea or pigeonpea (Rusinamhodzi *et al.,* 2012). Similarly, smallholder farmers generally intercrop maize with pigeonpea, cowpea, bambara groundnut and dry beans in countries such as Nigeria, Kenya and South Africa (Dania *et al.,* 2014; Egbe and Adeyemo, 2006; Dahmardeh, 2013; Kutu and Asiwe, 2010).

There are different types of intercropping spatial arrangements. These are, among others:

i. Row intercropping, which is growing two or more crops simultaneously with both crops planted in distinctive rows. Variations of row intercropping are inter-row intercropping (when the component crops are grown in separate rows between each other) and intra-row intercropping (when the component crops are grown within each row);
ii. Mixed intercropping, when growing two or more crops together without any distinct row arrangement;
iii. Relay intercropping, when planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage, but before harvesting;

iv. Strip intercropping, when growing two or more crops together in strips wide enough to permit separate management of crops, including use of machinery, but close enough for the crops to interact agronomically (Sullivan, 2003).

2.7.3.1 Advantages of intercropping

The intercropping system is being practised in many areas of South Africa, but mainly in Limpopo (Thobatsi, 2009). Intercropping in Limpopo is being practised on small farms in areas where land is limited, forcing smallholder farmers to produce different crops on the same piece of land (Nndwambi, 2015). Areas subjected to lower or uneven distribution of rainfall force smallholder farmers to practise intercropping since they try to maximise the use of water (Thobatsi, 2009).

Intercropping is superior compared to monoculture and mixed intercropping (Medupe, 2010). The advantages of intercropping over sole cropping and mixed intercropping are that competition for resources between species is less than within the same species (Edge and Idoko, 2012; Thobatsi, 2009). The principal reason for smallholder farmers practising intercropping is to increase profitability, create insurance against crop failure thereby minimising risk, better use of resources by plants of different heights, rooting depths and nutrient requirements, soil conservation, as well as low fixed cost of land as a result of a second crop in the same field (Thobatsi, 2009; Edge and Idoko, 2012; Dahmardeh, 2013; Nndwambi, 2015). Addo-Quaye *et al.* (2011), Pathak and Singh (2006) also reported that one of the most important reasons for smallholder farmers to intercrop is to minimise the risk of total crop failures (if one crop of a mixture fails, the other component crop may still be harvested), and to harvest different products for a family’s food and income.

Furthermore, Makgoga (2013) reported that the intercropping advantages include higher yields than sole crop yields. This is probably due to less intra-species competition, greater yield stability and more efficient use of environmental resources. Nndwambi (2015) also reported that intercropping maize and pigeonpea is a good option since pigeonpea is drought tolerant, can fix nitrogen and uses its deep root system to bring up nutrients from horizons inaccessible by the component crop. Akinnifesi *et al.,* cited by Makgoga (2013), stated that cereal/legume intercropping systems reduce the number of nutrients taken from the soil as compared to sole crops.

Kariaga (2004) also reported that intercropping of cereal with legumes is an excellent practice for reducing soil erosion and sustaining crop production.

Availability of moisture in the soil is one of the most crucial factors that determine the productivity of crops in the cropping system (Edge and Idoko, 2012). Makgoga (2013) reported that an intercrop of two crop species such as legume and cereal use water more efficiently than monoculture, especially if the component crops have different rooting patterns. Therefore, smallholder farmers who farm in regions with rainfall challenges, especially those in Limpopo, are encouraged to practise intercropping to maximise the use of water.

2.7.4 Benefit of pigeonpea in an intercropping system

Pigeonpea is one of the most widely adapted, stress tolerant, indigenous and nutritious grain legumes in warm to hot regions of Africa (Gwata and Siambi, 2009). The benefit derived from legumes as part of intercropping has been attributed to nutrients contribution to the component crops, especially nitrogen. Zerihun (2016) reported that continuous maize monoculture is one of the major factors causing a decline in crop productivity; therefore, inclusion of pigeonpea in intercropping plays a vital role in rehabilitating degraded land and depleted soil due to its capacity to fix nitrogen, delivering a high biomass production, and high litterfall. Other advantages of pigeonpea include the opportunity to grow crops simultaneously without causing land degradation, and higher water infiltration because of its rooting pattern (Zerihun, 2016). Intercropping systems involving pigeonpea and annual crops such as maize significantly improve yields and contribute to poverty alleviation among smallholder farmers (Adjei-Nsiah, 2012).

Makgoba (2013) reported that intercrops that have different rooting systems and nutrients uptake patterns result in a more efficient use of nutrients, mainly nitrogen uptake. For this reason, pigeonpea in an intercrop system takes up nutrients from the deeper soil layer to be utilised by the component crop due to its deeper rooting system. Pigeonpea in intercropping minimises the risk of crop failure due to its ability to produce grain under harsh environments imposed by drought and erratic or uneven rainfall distribution (Gwata and Siambi, 2009). According to Upadhyaya *et al.,* cited by Bambalele (2016), pigeonpea has an extensive root system, which enables it to be more compatible when intercropped with cereals or any other crops.

2.8 Pigeonpea-Maize Intercrop System

Cultivation of leguminous crop in intercropping with cereal crop has been recognised as one of the most effective ways how farmers can enhance crop productivity as well as minimise the risk of crop failure (Edge and Idoko, 2012). Pigeonpea is becoming increasingly important in smallholder farming systems in eastern and southern Africa, due to its ability to produce high grain yield despite uneven rainfall, high temperatures or infertile soil (Gwata and Siambi, 2009). The study by Egbe and Idoko (2012) revealed that the yield of pigeonpea genotypes varied with the cropping systems adopted. Their results further indicated that pigeonpea genotypes showed significant differences under intercropping compared to sole cropping in the pigeonpea-maize system (Egbe and Idoko 2012). Nndwambi (2015) observed that intercrop pigeonpea plots with 0 kg P ha^{-1} application rate produced the tallest plants, while lowest plant height was recorded under sole pigeonpea plots when no P was applied. Their result further indicated that the cropping system significantly influenced the grain yield of pigeonpea in both seasons with 37.1% higher pigeonpea grain yield from intercropped plots than in sole pigeonpea plot. A study conducted in Tanzania and Malawi showed mean grain yields of pigeonpea ranging from 172 to 740 kg ha^{-1} across several environments (Høgh-Jensen *et al*., 2007). Dwivedi *et al.* (2015) reported that intercropping gave higher pigeonpea equivalent yields than the sole crop, whereby the highest pigeonpea equivalent yield (2 t/ha) and Land Equivalent Ratio (1.89) was recorded.

The study by Mashingaidze *et al*. (2006) revealed that monocropping maize had significantly higher yields than intercropping maize. The result further indicated that the calculated total Land Equivalent Ratio (LER) for the two crops gave positive and higher than 1 values, which suggests a favourable grain yield advantage for the maize/pigeonpea intercrop. Similar LER values greater than 1.0 in maize/pigeonpea intercropping have been reported (Egbe and Adeyemo, 2006; Smith *et al.,* 2001), which showed strip intercropping advantages over monocropping. Marer *et al.* (2007) also stated that large yield advantages in the intercropping system were due to the component crops that differed in their use of natural resources and utilised them more efficiently, resulting in higher yields per unit area than those produced by their sole crops.

2.9 Assessment of Intercropping Productivity

2.9.1 Land equivalent ratio

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 (Thobatsi, 2009). An assessment of return on land 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). Intercrop yields are divided by the pure stand yields for each crop in the intercropping system and the two figures are added together (Sullivan, 2003). LER is defined as the total land area required under monocropping to give the yields that are obtained under the intercropping mixture. It is normally used for analysis of possible advantages of intercropping (Mead and Willey, 1980). The Land Equivalent Ratio is the most common index adopted in intercropping to measure the land productivity and is often used as an indicator to determine the efficacy of intercropping (Sullivan, 2003). Yield advantage in intercropping is attained through improved LER and is one of the key components in evaluating the effectiveness of the intercropping system (Hirpa, 2014).

The Land Equivalent Ratio is determined according to the following formula (Mead and Willey, 1980):

$$\text{LER} = \frac{\text{Intercropped yield of crop A}}{\text{Sole yield of crop A}} + \frac{\text{Intercrop yield of crop B}}{\text{Sole yield of crop B}}$$

An LER value of less than 1.0 indicates lower productivity of intercropping relative to sole crops; LER with the value of 1.0 shows no yield difference between intercropping and sole crops; and an LER value of greater than 1.0 shows a yield advantage of intercropping as compared to sole crops. Dahmardeh (2013) who explains that the greater LER could be attributed to the morphological differences of the two crops and the optimal utilisation of resources supports this. According to Ullah *et al.* (2007) the total LER for yield ranged between 1.06 to 1.58, which showed both a yield and growth advantage of intercropping. Similar LER values greater than 1.0 in maize/pigeonpea intercropping have also been reported (Egbe and Adeyemo, 2006; Smith *et. al.,* 2001). According to Quiroz and Marin (2003), there is a higher LER in a maize-based intercropping system compared to sole cropping. Addo-Quaye *et al*. (2011) found that LER was greater than unity implying that it will be more productive to intercrop maize-soybean than grow the respective crops in monoculture. Better use of growth resources was believed to be a major source of yield advantage from intercropping because of the complementary effect between component crops (Willey, 2006). Addo-Quaye *et al.* (2011) found that the productivity of the intercropping system indicated yield advantage of 2-63% as depicted by the LER of 1.02-1.63 showing efficient utilisation of land resource by growing the crops together.

CHAPTER 3

MATERIALS AND METHOD

3.1 Description of the Study Area

An experiment was conducted in two locations, namely the University of Limpopo Experimental Farm, Mankweng (UL Farm 23°53' 9.6" S, 29°43' 4. 8" E) and Ga-Molepo village (Ga-Thaba 24°01' 59" S, 29°47' 56" E) during the 2015/16 and 2016/17 seasons. These sites are under different rainfall and temperature regimes. The UL Farm is characterised by erratic low rainfall, which ranges between 450-650 annually and falls predominantly in summer. Ga-Thaba village is characterised by erratic low rainfall, which ranges between 450-500 mm per annum and falls predominantly in summer.

3.2 Research Design, Treatments and Procedures

The experiment unit was prepared by using a tractor to plough and harrow, to ensure a good seed bed. Five early-medium maturing varieties of pigeonpea, namely, ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661, ICEAP 01101-2 and maize variety (PAN 6479) were planted in the field. The pigeonpea varieties were selected as early maturing varieties from previous pigeonpea evaluation trials (Asiwe, 2016).

The first season planting was done on 13 and 14 January 2016 at the UL Farm and Ga-Thaba, respectively; and the second planting was done on 13 and 15 December 2016 at the UL Farm and Ga-Thaba, respectively. The trial was laid out in a split plot design. The main plot was cropping systems (intercrop and monocrop), the mono and mixed cropping included as standard control practices. The subplot was the variety, which consisted of five pigeonpea varieties (ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2) in three replications. The maize cultivar (PAN 6479) was planted at an inter-row spacing of 0.9 m and intra-row spacing of 0.3 m and row length of 4 m. The intercrops consisted of four rows of pigeonpea sandwiched between two rows of maize. The monocrop was consisting of four rows of pigeonpea planted at an inter-row spacing of 0.75 m and intra-row spacing of 0.5 m. The same plant arrangement and spacing was used in the two locations. The field plan is shown in Figure 3.2.

R_1	R_2	R_3	R_4	R_5	R_6
O	O	O	O	O	O
O	O	O	O	O	O
O	O	O	O	O	O
O	O	O	O	O	O

R_1	R_2	R_3	R_4	R_5	R_6
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X

a. Monocropping showing 6 rows of maize and 6 rows of pigeonpea

R_1	R_2	R_1	R_2	R_3	R_4	R_1	R_2
O	O	X	X	X	X	O	O
O	O	X	X	X	X	O	O
O	O	X	X	X	X	O	O
O	O	X	X	X	X	O	O

b. Strip intercropping showing 4 rows of pigeonpea sandwiched in between 2 rows of maize

O X O X O X O X O X O X O X O X O X
O X O X O X O X O X O X O X O X O X
O X O X O X O O X O X O X O X O X O
X O X O O X O O X O X X O X O O X X
O X O X X O X O O X O O X X O X O X
X O X O O O X O X O X O X O X O X O
X X O X 0 X X 0 0 0 0 X X O X 0 X 0 X 0

c. Mixed intercropping showing mixture of maize and pigeonpea

Figure 3.2: Trial plan (monocropping, strip intercropping and mix intercropping). Where X = Pigeonpea, O = Maize, R = Row

3.3. Crop Management

Roundup (isopropylamine salt of glyphosate) and Dual (S-metalachlor) at a rate of 3 L/ha and 0.5 L/ha, respectively, were used to control weeds before emergence. Manual weeding was done on growing weeds in the field when necessary. Karate (lambda-cyhalothrin) and Aphox (pirimicarb) at the rate of 1 L/ha and 500 g/ha were applied to control blister beetles on pigeonpea at flowering stage until pod maturity.

3.4 Data Collection

Sharma *et al.* (2010), Kumar *et al.* (2011) and Nndwambi (2015) listed relevant variables measured when assessing the agronomic performance of pigeonpea under intercropping. The following parameters were measured in the same way in the two locations and seasons:

3.4.1 Agronomic characteristics of pigeonpea

i. Number of days to 50% flowering:

   This was determined by counting the number of days from planting to the date of 50% crop stands has flowered. It was rated by field visual observation when 50% of the plant population has flowered.

ii. Number of days to 90% maturity

   This was determined by counting number of days taken from planting to when 90% of the crop stand has reached physiological maturity. It was rated by field visual observation when 90% of pods change their colour from green to brown.

iii. Plant height (cm)

   Five plants at maturity were tagged randomly from middle rows for sampling; the height was measured using a measuring tape and recorded from five tagged plants.

iv. Number of primary branches

   Five plants were tagged randomly from middle rows for sampling. Number of primary branches of the five tagged plants was counted and mean number of primary branches was calculated.

v. Pod length (cm)

Pod length was measured from five pods collected from each of five tagged plants. Then the average was calculated**.**

vi. Number of pods per plant

Fully developed pods from five tagged plants were counted and then the average was calculated.

vii. Number of seeds per pod

Seeds from five tagged plants were counted. This figure was then divided by the number of pods from those five plants.

viii. Grain yield (kg/ha)

The grain yield was determined by harvesting two middle rows and threshed manually to record grain yields per plot using electronic weighing balance and the net yield was converted to kg ha^{-1}.

ix. Hundred seed weight (g)

Two samples of hundred good seeds were randomly counted and weighed in grams using digital scale. Their average was computed.

3.4.2 Agronomic characteristics of maize

i. Number of days to 50% tasselling

This was determined from each plot by counting the number of days taken from the date of 50% emergence to reach 50% tasselling in the field.

ii. Number of days to 50% silking

This was determined from each plot by counting the number of days taken from the date of 50% emergence to reach 50% silking in the field.

iii. Plant height at harvest (cm)

Five plants at maturity in the net plot were selected randomly and measured with a measuring tape and recorded. Then the average was calculated.

iv. Length of a cob (cm)

Five plants were tagged randomly from the middle rows of maize for sampling. Five cobs (each plot) from plants at maturity were selected randomly and measured using a metre rule and the average was calculated.

v. Number of cobs per plant

The number of cobs on the five plants was counted also recorded and averaged.

vi. Grain yield (kg ha^{-1})

The grain yield was determined by harvesting two middle rows and threshed manually to record grain yield per plot. This was then used to extrapolate yield on a hectare basis.

vii. Stover yield (kg ha^{-1})

Crop was harvested at physiological maturity, exposed to sun drying and then weighed with the help of a weighing balance to record the total biomass per plot.

3.4.3. Assessing intercrop productivity

For assessing intercrop productivity, the following parameter was taken. The Land Equivalent Ratio (LER) was calculated from the relative yield of pigeonpea and maize with their sole treatments by using the following formulas:

$$\text{LER (Strips)} = \frac{\text{Intercropped yield of crop A}}{\text{Sole yield of crop A}} + \frac{\text{Intercrop yield of crop B}}{\text{Sole yield of crop B}}$$

$$\text{LER (Mixed)} = \frac{\text{Mixed intercropping yield}}{\text{Monocropping yield}} + \frac{\text{Mixed intercropping yield}}{\text{Monocropping yield}}$$

A Land Equivalent Ratio value of less than 1.0 indicates lower productivity of intercropping relative to sole crops; LER with the value of 1.0 shows no yield difference between intercropping and sole crops, and an LER value of greater than 1.0 shows yield advantage of intercropping as compared to sole crops.

3.5. Data Analysis

Data for agronomic characteristics obtained from the two locations and seasons were subjected to analysis of variance using Statistix 10.0 software to determine the performance of pigeonpea and maize under strip intercropping across locations and seasons and interaction effects of the intercropping treatment, pigeonpea varieties and season. Means that showed significant differences were separated using Least Significant Difference (LSD) at the probability level of 5%.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Weather Results during the 2015/16 and 2016/17 Season at the University of Limpopo Experimental Farm (UL Farm)

The first trial was planted on 13 January 2016. In the first season, during the months of January to March, the temperature was very high with an average of 28-30ºC coupled with high rainfall (126.73 mm), especially during the month of March (Figure 4.1). High rainfall during the vegetative stage accelerated vegetative growth, leading to a high number of primary branches and pods per plant. From April to June, there was a reduction in temperature (26-19ºC) with lower monthly rainfall of about 2-5 mm (Figure 4.1). The second season was longer since planting was done on 13 December 2016 (Figure 4.2). Rainfall, was higher during December and January 2016/17 season, with a mean of 120.90 mm and 101.09 mm, respectively. The temperature show the period ranging between 25-27ºC (Figure 4.2). Adequate rainfall, especially after planting, promoted crop establishment and reduced crop failure. However, during the month of February, there was a reduction in rainfall until March (40-23 mm) with reduction temperature. Towards the end of the season, there was also poor rainfall distribution, coupled with high temperatures in the month of May (Figure 4.2). The first season was very hot and had lower rainfall as compared to second season (Figures 4.1 and 4.2).

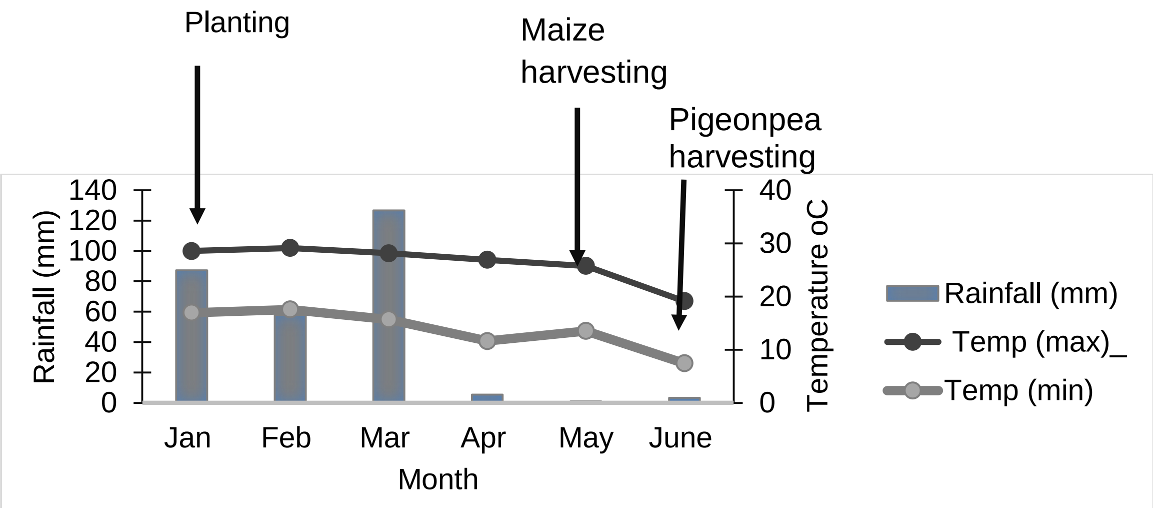

Figure 4.1: Mean monthly rainfall, minimum and maximum temperatures during the 2015/16 season at the University of Limpopo Experimental Farm (UL Farm)

Source: Agricultural Research Council - ISCW and the University of Limpopo Weather Station records

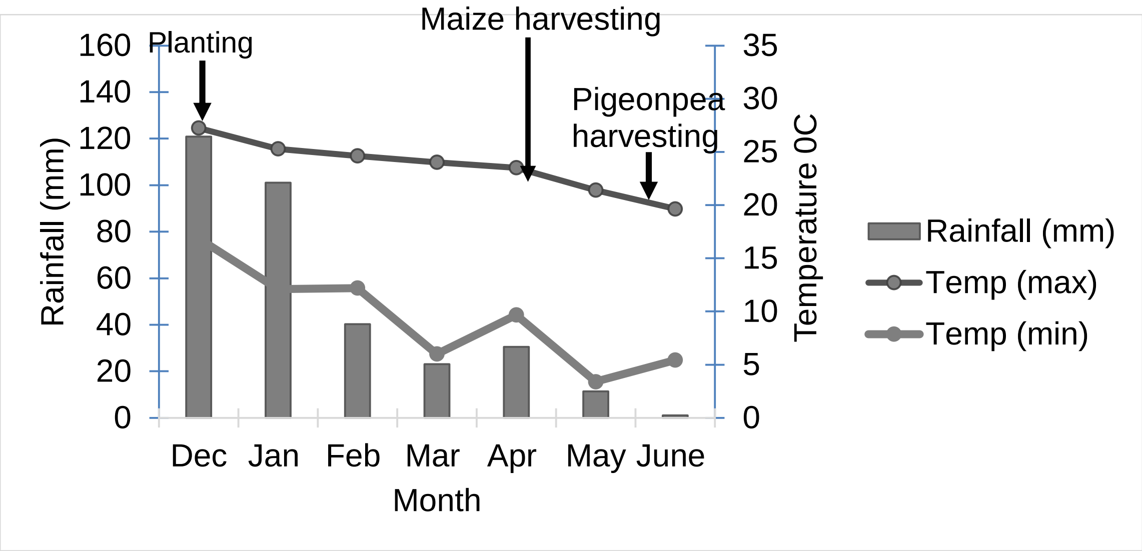

Figure 4.2: Mean monthly rainfall, minimum and maximum temperature during the 2016/17 season at the University of Limpopo Experimental Farm (UL Farm).
Source: Agricultural Research Council - ISCW and the University of Limpopo Weather Station records

4.2 Performance of Pigeonpea Varieties at the University of Limpopo Experimental Farm (UL Farm)

4.2.1 Number of days to 50% flowering

The interaction between variety x cropping system x season (v x cropping system (CS) x s) showed significant ($P \leq 0.05$) differences (Table 4.1). During the 2015/16 season, varieties (ICEAP 00661, ICEAP 01101-2 and ICEAP 87091) attained 50% flowering between 120 to 140 days under monocropping and strip intercropping respectively (Figure 4.3). The minimum days to attain 50% flowering during the 2015/16 season was observed on ICEAP 001284 and ICEAP 00604, which ranged between 100 to 120 days under strip intercropping and monocropping (Figure 4.3). Variation in number of days to 50% flowering was due to varietal characteristics. A similar outcome was observed by Khaki (2014) who reported significant differences on pigeonpea due to varietal characteristics in different seasons.

During the 2016/17 season, none of the varieties under strip intercropping differed significantly; however, under monocropping, maximum days to reach 50% flowering was observed on ICEAP 01101-2 (120 days) as compared to four varieties (ICEAP 001284, ICEAP 87091, ICEAP 00661 and ICEAP 00604), which took less than 120 days to attain 50% flowering (Figure 4.3). Maximum days to 50% flowering observed on ICEAP 01101-2 were probably due to a prolonged vegetative phase. This agrees with the findings of Ojwang *et al.* (2016) who observed that genotypes that had a short vegetative phase attained 50% flowering earlier than those that had prolonged vegetative growth. During both seasons, pigeonpea varieties under mixed intercropping responded the same way in the number of days to 50% flowering, which ranged between 100 -130 days (Figure 4.3).

During both seasons at the UL Farm, the results revealed that there were significant ($P \leq 0.05$) differences in the number of days to 50% flowering across pigeonpea varieties (Table 4.1). Variety (ICEAP 01101-2) reached the maximum days to flowering at 125.44 days, followed by ICEAP 87091 and ICEAP 00661, where this was reached at 120 days (Table 4.3). The minimum number of days to 50% flowering was observed for ICEAP 001284 and ICEAP 00604 at 109.17 and 110.17 days, respectively (Table 4.3). The two varieties (ICEAP 00661 and ICEAP 87091) had medium vegetative growth (Table 4.3). Variation in the number of days to 50% flowering was due to varietal characteristics. Egbe et al. (2013) who observed significant differences on pigeonpea varieties due to their genetic makeup observed a similar outcome.

Pigeonpea varieties' response to the number of days to 50% flowering was not significantly ($P \geq 0.05$) affected by cropping systems (Table 4.1). This agrees with the previous findings of Sharma *et al*. (2010) who reported that the cropping system did not affect the number of days to 50% flowering. Table 4.3 depicts that there were significant ($P \leq 0.05$) differences in the number of days to 50% flowering as influenced by seasons, where the longest time to 50% flowering of 119.71 was observed during the 2016/17 season compared to 113.16 days, which was observed during the 2015/16 season. The higher number of days observed for 2016/17 might be ascribed to the cooler day-time temperatures, which were prevalent during the 2016/17 season (Figure 4.2). These findings were also line with outcomes of Slim *et al. (*2007) who had reported that cool temperatures lengthen the time until flowering, while elevated temperatures shorten the duration until flowering.

Table 4.1: Analysis of variance for number of days to 50% flowering during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	22.87	11.43		
Variety (V)	4	2475.27	618.82	108.09	0.0000*
Error Rep*V	8	45.80	5.73		
CS	2	510.47	255.23	23.63	0.0640ns
V*CS	8	1272.20	159.03	14.72	0.0000*
Error Rep*V*CS	20	216.00	10.80		
Season (S)	1	6.94	6.94	0.47	0.0364*
V*S	4	673.89	168.47	11.50	0.0000*
CS*S	2	1390.82	6 95.41	47.49	0.0000*
V*CS*S	8	342.51	42.81	2.92	0.0154*
Error R*V*CS*S	30	439.33	14.64		
Total	89	7396.10			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

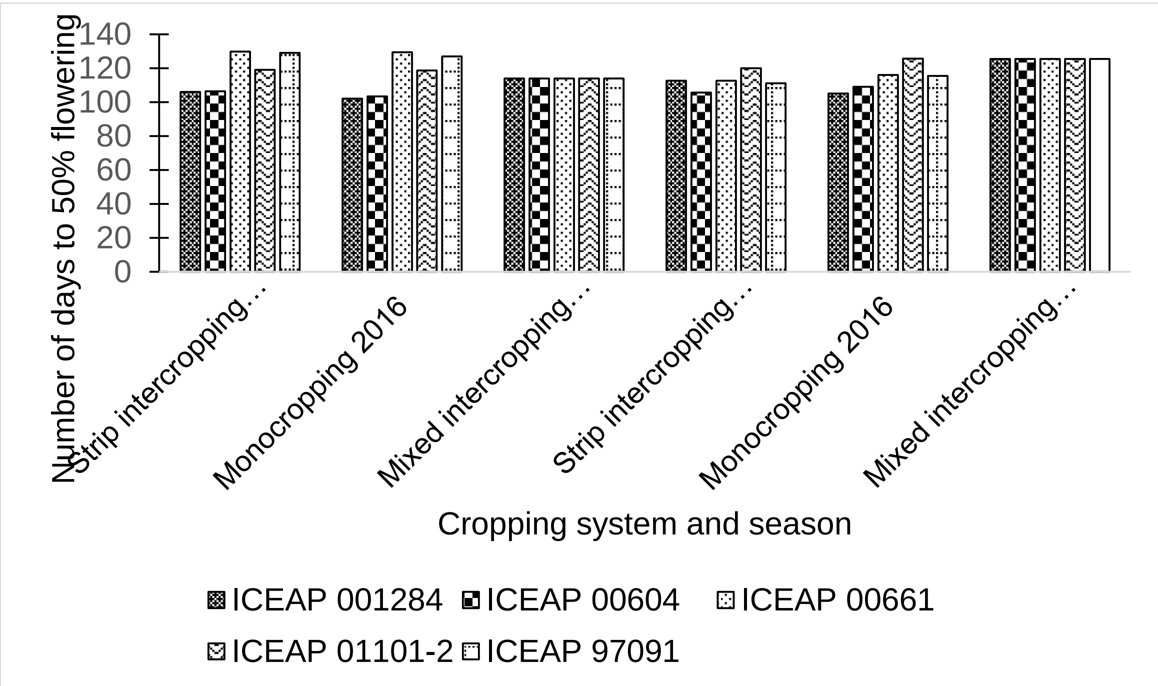

Figure 4.3: Interaction of variety x cropping system x season for number of days to 50% flowering during the 2016 and 2017 seasons

4.2.2 Number of days to 90% physiological maturity

The interaction between variety x cropping system (V x CS) showed significant ($P \leq 0.05$) differences (Table 4.2). Variety (ICEAP 001284) exhibited the shortest number of days to reach 90% physiological maturity under all cropping systems, which was recorded as follows: 174.67, 182. 33 and 190.00 days respectively monocropping, strip intercropping and mixed intercropping (Figure 4.4). Longer number of days to 90% physiological maturity under the three cropping systems was obtained by ICEAP 01101-2, which were 191.50, 191.83 and 195.00 respectively for monocropping, mixed intercropping and strip intercropping (Figure 4.4). Differences in 90% physiological maturity among varieties were due to varietal characteristics. Similar results were reported by Slim *et al*. (2007). A dwarf variety such as ICEAP 001284 matured early due to its short vegetative growth, whereas a taller variety such as ICEAP 01101-2 matured late because it continued to grow indeterminately until it reached physiological maturity. This is in line with outcomes of Ojwang *et al.* (2016) who reported differences in physiological maturity due to genetic makeup. Three varieties (ICEAP 00604, ICEAP 87091 and ICEAP 00661) became matured between 185 to 193 days (Figure 4.4).

The results revealed that there were significant ($P \leq 0.05$) differences on the interaction between cropping system x season (CS x S) (Table 4.2). Mixed intercropping exhibited the longest number of days of 195 to reach 90% physiological maturity and was significantly higher than strip intercropping and monocropping, which had shorter period of 187 and 186, respectively during 2015/16 season (Figure 4.5). The longest period of 191 days to attain 90% physiological maturity during 2016/17 season were recorded for strip intercropping and monocropping, however, mixed intercropping had the shortest days of 187.00 to attain maturity (Figure 4.5). The longest period to reach 90% physiological maturity observed during the 2016/17 sea was possibly due to high temperatures that were prevalent at the UL Farm during pod ripening (Figure 4.2). These findings agree with previous study outcomes by Khaki (2014) who reported that high temperatures during pod ripening lengthen the maturity of pigeonpea genotypes.

The significant ($P \leq 0.05$) differences in number of days to 90% physiological maturity were observed among five pigeonpea varieties (Table 4.2). Variety (ICEAP 001284) had the shortest growth period (182.50 days) and was significantly ($P \leq 0.05$) different from four varieties, which ranged between 190.11 to 193.72 days (Table 4.3). In Table

4.3 below, ICEAP 01101-2 had the longest growth period of 193.72 days. The results showed that the number of days to 90% maturity across different varieties was influenced by the number of days to 50% flowering. Variety (ICEAP 001284) exhibited the minimum number of days to 50% flowering; and therefore, obtained its physiological maturity earlier, whereas ICEAP 01101-2 recorded the maximum number of days to 50% flowering and this led to late physiological maturity. This is in line with the findings of Hluyako (2015) who observed that early flowering results in early maturity, whereas late flowering results in late physiological maturity. Pigeonpea varieties' response to the number of days to 90% maturity was not significantly ($P \geq 0.05$) affected by the cropping systems (Table 4.2). There were significant ($P \leq 0.05$) differences between seasons with respect to days of 90% physiological maturity (Table 4.3). The highest number of days of 192.49 was observed during the 2016/17 season compared to 186.40 days during the 2015/16 season (Table 4.3).

Table 4.2: Analysis of variance for number of days to 90% physiological maturity during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	13.36	6.68		
Variety (V)	4	1233.56	308.39	10.59	0.0028*
Error Rep*V	8	232.98	29.12		
Cropping system (CS)	2	134.82	67.41	3.90	0.1370ns
V*CS	8	804.18	100.52	5.82	0.0007*
Error Rep*V*CS	20	345.33	17.27		
Season (S)	1	0.18	0.18	0.00	0.0244*
V*S	4	144.49	36.12	0.99	0.4295ns
CS*S	2	798.16	399.08	10.91	0.0003*
V*CS*S	8	335.51	42.00	1.15	0.3627
Error R*V*CS*S	30	1097.67	36.59		
Total	89	5140.22			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

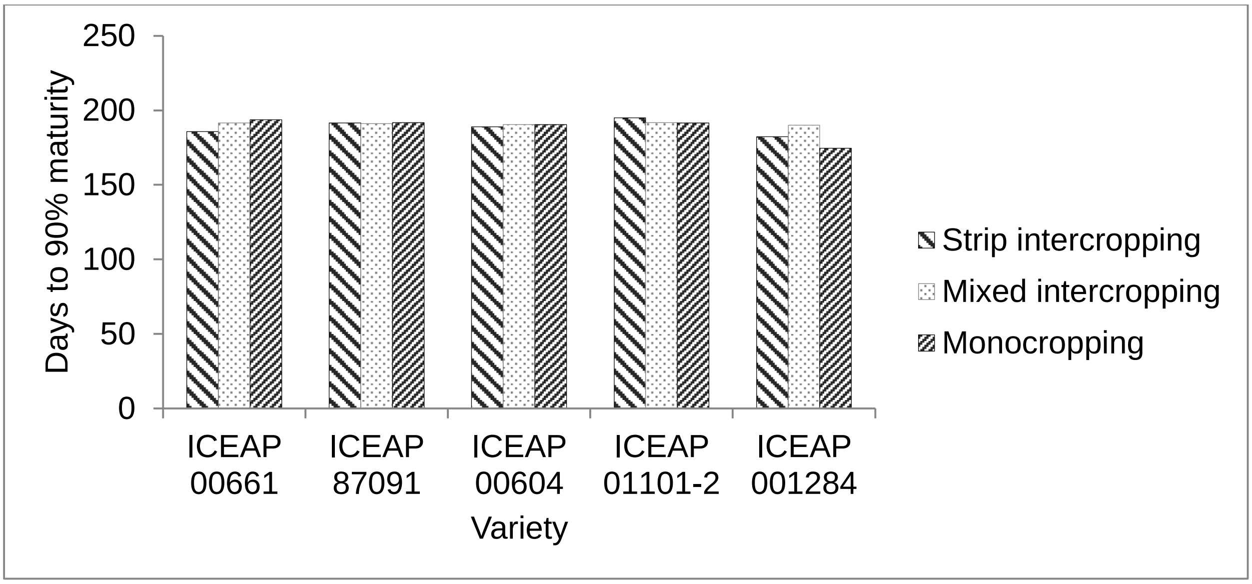

Figure 4.4: Interaction of variety x cropping system for number of days to 90% maturity during the 2016 and 2017 seasons

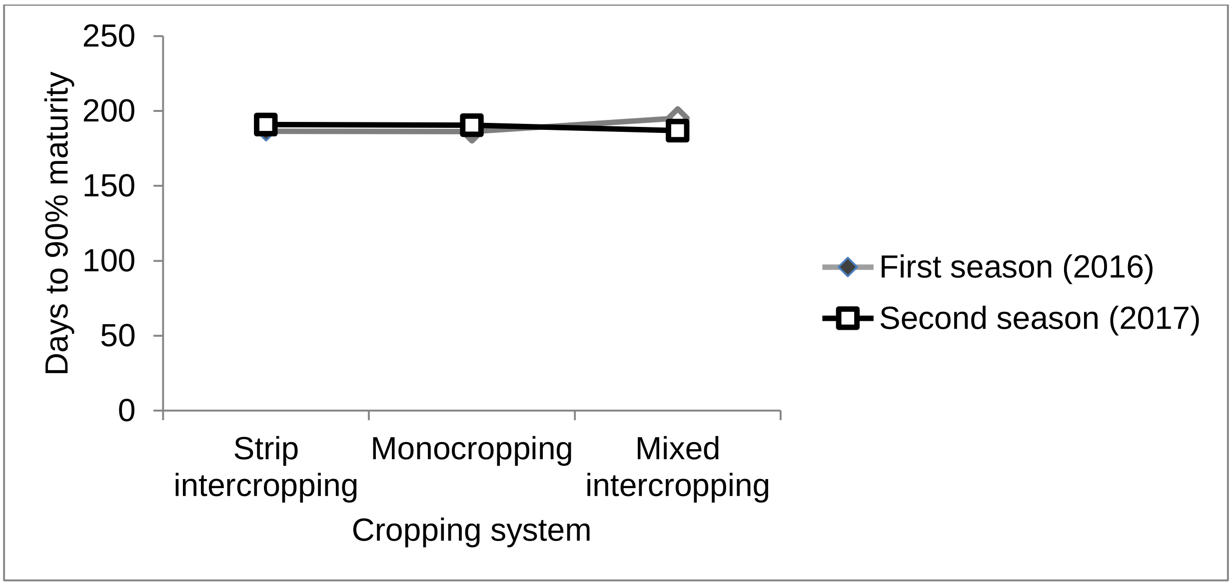

Figure 4.5: Interaction of cropping system x season for number of days to 90% maturity during the 2016 and 2017 seasons

Table 4.3: Effect of variety, cropping system and season on phenological development of pigeonpea during the 2015/16 and 2016/17 seasons

Variety (V)	Number of days to 50% flowering	Number of days to 90% maturity	Duration of reproductive development
ICEAP 00661	120.00[b]	190.39[a]	70.39[c]
ICEAP 87091	120.00[b]	191.50[a]	71.50[c]
ICEAP 01101-2	125.44[a]	193.72[c]	68.28[d]
ICEAP 00604	110.94[c]	190.11[a]	82.17[a]
ICEAP 001284	109.17[c]	182.50[b]	73.33[b]
Grand mean	117.11	189.44	72.93[b]
SEM	0.7976	1.7988	1.3210
	Cropping system (CS)		
Monocropping	115.63[a]	188.43[a]	72.80[a]
Strip Intercropping	114.00[a]	188.73[a]	74.73[a]
Mixed intercropping	116.67[a]	188.17[a]	71.50[a]
SEM	0.8485	1.0729	1.6532
	Season (S)		
2015/16	119.71[a]	186.40[b]	66.69[b]
2016/17	113.16[b]	192.49[a]	79.24[a]
SEM	0.8068	1.2752	0.3214

Means followed by the same letter in each column do not differ significantly at P ≤ 0.05. SEM = Standard error of means

4.2.3 Plant height (cm)

Plant height was significantly (P ≤ 0.05) affected by the interaction between variety x cropping system x season (V x CS x S) (Table 4.4). During the 2015/16 season, there were no significant differences in terms of plant height among varieties under strip intercropping. However, during the 2016/17 season, the highest plants under strip intercropping were observed for ICEAP 87091, ICEAP 00661 and ICEAP 01101-2 with mean heights of 119.33 cm, 120.67 cm and 126.67 cm, respectively (Figure 4.6), whereas the lower heights were recorded for ICEAP 00604 and ICEAP 001284 with means of 114.00 cm and 105.00 cm, respectively (Figure 4.6). According to Egbe and Vange (2008), plant height is known to be affected by maturity duration, genetic factors and the environment. Significant differences in plant height may be attributed to maturity duration and genetic factors. Five pigeonpea varieties have different heights and this was due to the genetic makeup of the varieties.

During the 2015/16 season under monocropping, the highest plant height of 154.00 cm was observed for ICEAP 00661, followed by ICEAP 97091 (141.00 cm) and ICEAP 00604 (136.67 cm), whereas lower heights were observed on ICEAP 00604 (123.00 cm) and 01101-2 (116.33 cm) (Figure 4.6). The taller plant heights of 116.33 cm, 114.67 cm and 113.33 cm during the 2016/17 season under monocropping was observed for ICEAP 01101-2, ICEAP 00661 and ICEAP 87091, respectively, whereas the shortest plant heights were recorded for ICEAP 00604 (108.67 cm) and ICEAP 001284 (98.33 cm) during the 2016/17 season (Figure 4.6). During the seasons 2015/16 and 2016/17, plant heights under mixed intercropping responded the same way, but plant heights during the 2015/16 season under mixed intercropping were significantly higher than the plants that were recorded during the 2016/17 season under the mixed intercropping system (Figure 4.6). Achieving taller plants during the 2015/16 season was probably due to the prolonged vegetative phase during that season. This was also evidenced by Hluyako (2015) who explained that increase in plant height is associated with longer days to flower due to a prolonged vegetative phase.

There were significant ($P \leq 0.05$) differences in plant heights across pigeonpea varieties in both seasons at the UL Farm (Table 4.4). This agrees with findings of Egbe (2005) who observed significant differences of plant height among pigeonpea varieties in two seasons. Five pigeonpea varieties had a different height due to their genetic makeup. This is similar to the findings of Hluyako (2015) who reported that genotypic differences influence plant height. The taller plant height of 149.50 cm was recorded for ICEAP 01101-2, compared to ICEAP 001284 (134.89 cm) (Table 4.6). Varieties (ICEAP 00604, ICEAP 00661 and ICEAP 87091) had plant heights of 140.70 cm, 142.00 cm and 143.94 cm, respectively (Table 4 6). The taller plant observed for ICEAP 01101-2 was probably because it having matured later than the other varieties; therefore, it is indeterminate, while a shorter plant was observed for ICEAP 001284 and ICEAP 00604 because they are dwarf type varieties, which are determinate and matured early. This agrees with findings of Ojwang *et al.* (2016) who observed that long-duration genotypes are generally tall, because they have a prolonged vegetative stage, while the shorter durations varieties are comparatively short in stature due to their short vegetative growth phase.

Pigeonpea plant height was significantly ($P \leq 0.05$) affected by cropping systems (Table 4.4). The mean pigeonpea plant height in mixed intercropping resulted in the shortest plant height of 103.50 cm as compared to other cropping systems (strip intercropping and monocropping), which resulted in 171.97 cm and 151.17 cm, respectively (Table 4.6). Higher plant height in strip intercrop plots and monocrop was probably due to low competition for resources both above ground and below ground as compared to mixed cropping.

Table 4.6 depicts that there were significantly ($P \leq 0.05$) different plant heights, which were influenced by seasons, where the taller plant of 171.29 cm was observed during the 2015/16 season, compared to a plant height of 113.13 cm during the 2016/17 season. The superior performance of plant height at the UL Farm during the 2015/16 season was probably due to higher temperatures during the growing phase (Figure 4.1). During the 2015/16 season, the UL Farm experienced higher temperatures from the flowering stage in March until physiological maturity in May (Figure 4.1) and the rainfall was better distributed until March. This agrees with previous findings of Silim *et al.* (2007), when authors reported that plant height in pigeonpea is positively correlated to temperature; under higher temperatures, plants are tall and a decrease in temperature results in a reduction of plant height. However, these results are in contradiction with the findings of Ojwang *et al.* (2016) who reported that an increase in mean temperatures during the flowering phase leads to a reduction in plant height.

Table 4.4: Analysis of variance for plant height of pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	268	134.00		
Variety (V)	4	1744	436.00	6.47	0.0126*
Error Rep*V	8	539	67.40		
Cropping system (CS)	2	15764	7882.20	113.22	0.0000*
V*CS	8	1517	189.7 0	2.72	0.0330*
Error Rep*V*CS	20	1392	69.60		
Season (S)	1	76097	76096.50	1219.28	0.0000*
V*S	4	160	39.90	0.64	0.6385ns
CS*S	2	11579	5789.40	92.76	0.0000*
V*CS*S	8	1194	149.30	2.39	0.0398*
Error R*V*CS*S	30	1872	62.40		
Total	89	112127			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

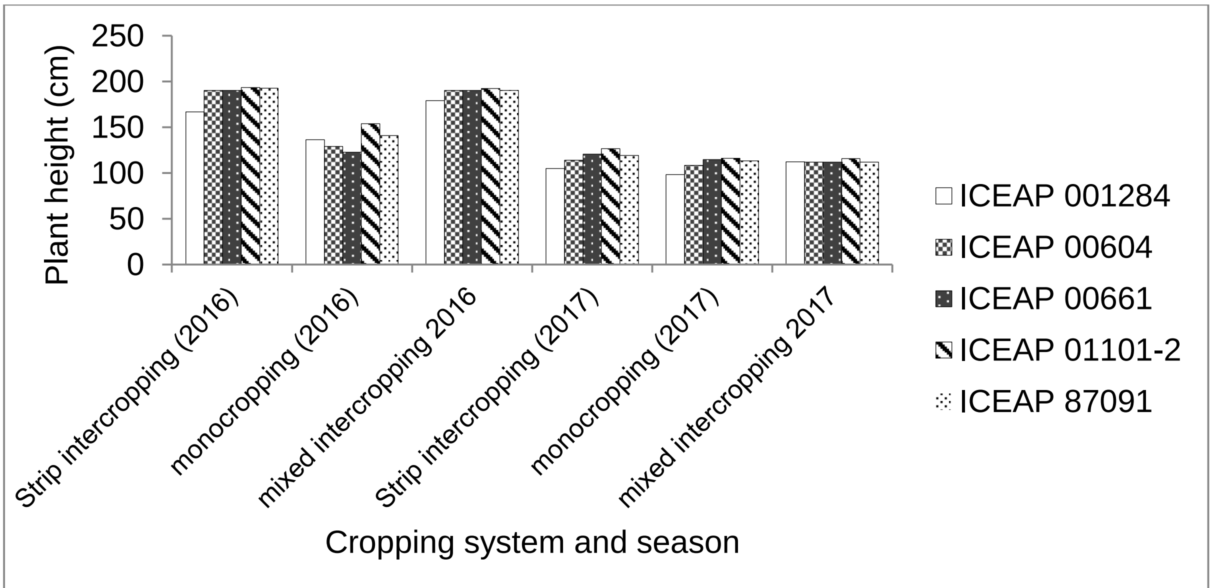

Figure 4.6: Interaction of variety x cropping system x season for plant height during the 2016 and 2017 seasons

4.2.4 Number of primary branches

The interaction between variety x cropping system x season (V x CS x S) showed no significant ($P \geq 0.05$) differences in the number of primary branches. However, significant ($P \leq 0.05$) differences were observed on the interaction between cropping system x season (CS x S) (Table 4.5). A higher number of primary branches with a mean of 17.60, 16.33 and 15.93, respectively, were observed for strip intercropping, mixed intercropping and monocropping during 2015/16. Number of primary branches were significantly higher during the 2016/17 season than 2015/16 for all cropping systems (Figure 4.7). The higher number of primary branches observed during 2015/16 was probably due to the higher rainfall pattern during that season, which resulted in higher plant height (Figure 4.1). These results align with previous findings of Egbe (2005) who reported that numbers of branches are positively correlated with plant height. A similar outcome was observed by Hardev (2016) who obtained a positive correlation ($r = 0.05$) between the number of primary branches and plant height, where a higher number of primary branches were observed due to higher plant height. Pigeonpea varieties showed no significant ($P \geq 0.05$) differences in the number of primary branches per plant; however, cropping systems and seasons exerted a significant ($P \leq 0.05$) effect (Table 4.5). Cropping systems exerted no significant ($P \leq 0.05$) differences on the number of primary branches.

Seasons revealed significant ($P \leq 0.05$) differences, where the highest number of primary branches of 16.62 were recorded for 2015/16 compared to 9.84 during the 2016/17 season (Table 4.6). Higher numbers of primary branches for the 2015/16 season could be due to higher rainfall patterns during March 2015/16, which supported growth beyond that growth (Figure 4.1). These findings are in close conformity with the findings of Khaki (2014) who reported that high moisture level during the flowering stage accelerates vegetative growth.

Table 4.5: Analysis of variance for number of primary branches on pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	23.27	11.63		
Variety (V)	4	82.38	20.59	2.33	0.1432ns
Error Rep*V	8	70.62	8.83		
Cropping system (CS)	2	114.87	57.43	4.94	0.0180*
V*CS	8	49.02	6.13	0.53	0.8222ns
Error Rep*V*CS	20	232.44	11.62		
Season (S)	1	1033.61	1033.61	140.73	0.0000*
V*S	4	49.67	12.42	1.69	0.1782ns
CS*S	2	57.22	28.61	3.90	0.0313*
V*CS*S	8	106.67	13.33	1.82	0.1132ns
Error R*V*CS*S	30	220.33	7.34		
Total	89	2040.10			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

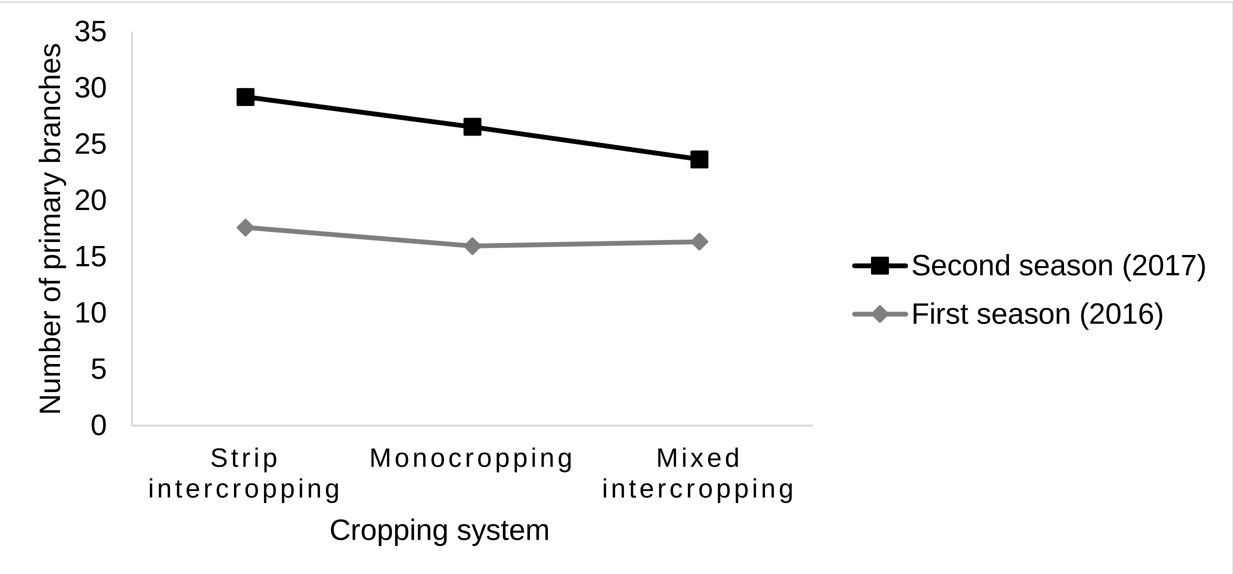

Figure 4.7: Interaction of cropping system x season for the number of primary branches during the 2016 and 2017 seasons

Table 4.6: Effect of variety, cropping system and season on phenological development of pigeonpea during 2015/16 and 2016/17 seasons

Variety (V)	Plant height (cm)	Number of primary branches per plant
ICEAP 00661	142.00[ab]	13.22[a]
ICEAP 87091	143.94[ab]	12.17[a]
ICEAP 01101-2	149.50[a]	14.28[a]
ICEAP 00604	140.70[bc]	12.17[a]
ICEAP 001284	134.89[c]	14.33[a]
Grand mean	142.21	13.233
SEM	2.7369	0.9904
Cropping system (CS)		
Monocropping	151.17[a]	13.267[ab]
Strip Intercropping	171.97[a]	14.600[a]
Mixed intercropping	103.50[b]	11.833[b]
SEM	2.1543	0.8802
Season (S)		
2015/16	171.29[a]	16.622[a]
2016/17	113.13[b]	9.844[b]
SEM	1.6655	0.5713

Means followed by the same letter in each column do not differ significantly at P ≤ 0.05. SEM = Standard error of means

4.2.5 Number of pods per plant

The interaction between variety x cropping system x season (V x CS x S) showed no significant (P ≤ 0.05) differences in number of pods per plant; however, significant (P ≤ 0.05) differences were observed on the interactions between variety x cropping system (V x CS) as well as the interactions between cropping system x season (CS x S) (Table 4.7). In Figure 4.8 below, under strip intercropping, variety ICEAP 01101-2 (291.33 pods) produced higher number of pods per plant than the other four varieties, ICEAP 00604 (230.50 pods), ICEAP 001284 (248.67 pods) and ICEAP 87091 (238.33 pods), while the lowest (225.00 pods) was recorded for ICEAP 00661.

Five varieties responded the same way under mixed intercropping; however, under monocropping, varieties (ICEAP 01101-2 and ICEAP 001284) produced higher numbers of pods, 175.83 and 159.67, respectively (Figure 4.8). The lower number were observed on ICEAP 00604 (103.50 pods), ICEAP 87091 (108.17 pods) and ICEAP 00661 (112.67 pods) under monocropping (Figure 4.8). Variations in the number of pods per plant among varieties might be due to the genetic makeup of varieties. These results are in conformity with the findings of Cheboi *et al*. (2016) who recorded significant differences in the number of pods per plant due to their genetic makeup. Srichandan and Mangaraj, 2015; Nagraj et al., 2016 also reported that genetic factors of the varieties were responsible for the differences observed among the number of pods.

Figure 4.9 shows that the interaction between cropping system x season (CS x S) were significant ($P \leq 0.05$). Higher number of pods per plant (244.30 and 248.93) was recorded under strip intercropping for 2015/16 and 2016/17 seasons, respectively. The lowest number of pods per plant during the 2015/16 season was recorded under monocropping and mixed intercropping (154.07 and 126.87 pods) respectively (Figure 4.9). Lower number of pods (109.87 and 96.27) was recorded under monocropping and mixed intercropping, respectively, during the 2016/17 season (Figure 4.9). Reduction in the number of pods per plant under mixed intercropping was probably due to high competition for growth resources (light, water and nutrients). This also suggests reduced interplant competition under strip intercropping relative to the other two cropping systems.

Analysis of variance revealed significant ($P \leq 0.05$) difference among varieties for the number of pods per plant (Table 4.7). Similar results were reported by Cheboi *et al. (*2016) and Hardev (2016). ICEAP 01101-2 variety outperformed the rest with an average of 206.61 pods, followed by ICEAP 001284 and ICEAP 00604 with 197.50 and 157.78 pods, respectively (Table 4.9). The varieties with the lowest number of pods per plant were ICEAP 00661 and ICEAP 87091 with 147.28 and 142.50 pods, respectively. Variation in the number of pods per plant could be due to the genetic makeup of varieties and the response to other growth factors such as water and nutrients. These results are in conformity with the findings of Cheboi *et al*. (2016) who recorded differences in the number of pods per plant due to their genetic makeup.

Cropping systems and seasons significantly ($P \leq 0.05$) affected the number of pods per plant (Table 4.7). The highest number of pods (208.37) was observed under strip intercropping, while the lowest number (192.83 pods) was recorded under monocropping, followed by mixed intercropping, which had a mean of 109.80 pods (Table 4.9). The number of pods per plant under strip intercropping was significantly higher than under mixed intercropping. This might have resulted from low inter- and intra-competition for plant growth factors.

Table 4.7 depicts that there were significant ($P \leq 0.05$) differences in the number of pods per plant as influenced by seasons. Significant differences observed were probably due to the unequal amount of rainfall observed during the growing period in the two years (Figures 4.1 and 4.2). The number of pods per plant was significantly higher during the 2015/16 than 2016/17 seasons, which had a mean of 208.53 and 132.13 pods, respectively (Table 4.9). The first season at the UL Farm produced a higher number of pods per plant than the second season. This may have been contributed by the moderate rainfall of March 2015/16 during the podding stage, which led to an increase in the number of pods per plant (Figure 4.1). The findings of Silim *et al.* (2007) validates this observation. They reported that high moisture level favoured vegetative growth, leading to a higher number of branches, a higher number of flowers and finally, a higher number of pods per plant.

Table 4.7: Analysis of variance for number of pods per plant of five pigeonpea during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	1022	511		
Variety (V)	4	63324	15831	4.06	0.0436*
Error Rep*V	8	31168	3896		
Cropping system (CS)	2	168512	84256	74.18	0.0000*
V*CS	8	43538	5442	4.79	0.0021*
Error Rep*V*CS	20	22717	1136		
Season (S)	1	131332	131332	93.24	0.0000*
V*S	4	562	140	0.10	0.9817ns
CS*S	2	12325	6162	4.38	0.0215*
V*CS*S	8	8474	1059	0.75	0.6462ns
Error R*V*CS*S	30	42255	1409		
Total	89	525228			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

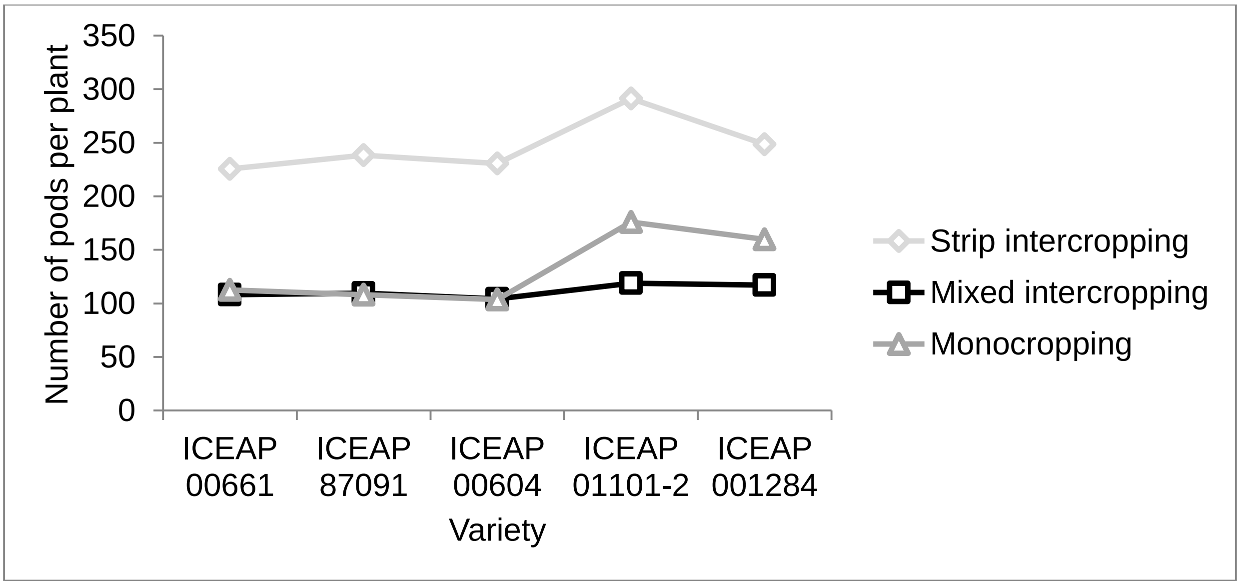

Figure 4.8: Interaction of cropping system x variety for number of pods per plant during the 2016 and 2017 seasons

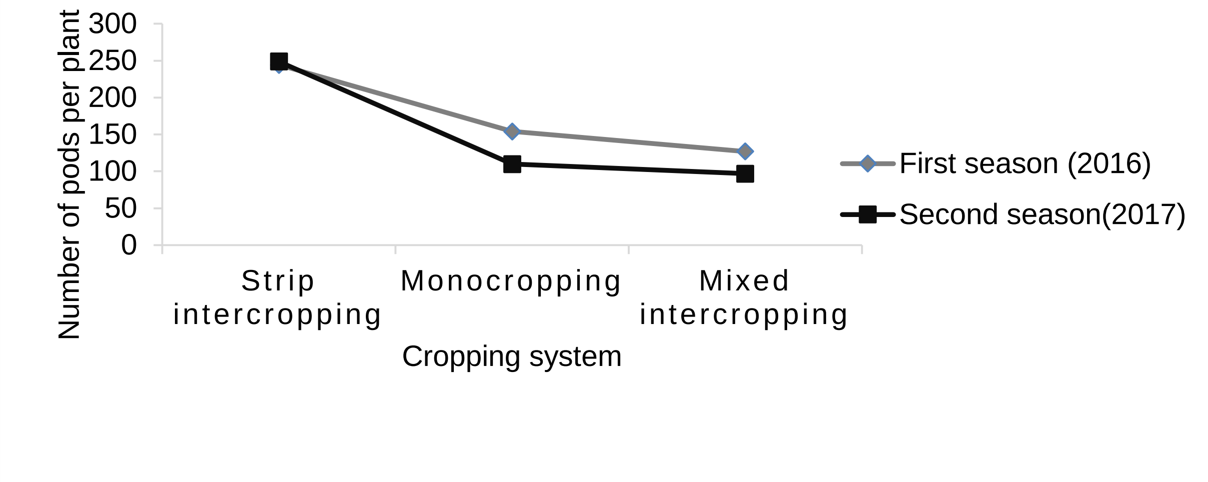

Figure 4.9: Interaction of cropping system x season for the number of pods per plant during the 2016 and 2017 seasons

4.2.6 Pod length (cm)

The interaction between variety x cropping system x season (V x CS x S) showed no significant ($P \geq 0.05$) differences; however, significant ($P \leq 0.05$) differences were observed on the interaction between cropping system x season (CS x S) (Table 4.8). Season 2016/17 produced the longest pods under all cropping systems, strip intercropping (6.20 cm), monocropping (6.20 cm) and mixed intercropping (5.66 cm), and was significantly higher than strip intercropping (5.20 cm), monocropping (5.40 cm) and mixed intercropping (4.87 cm) during the 2015/16 season (Figure 4.10). Longer pods observed during the 2016/17 season were probably vigorous due to the high rainfall, which promoted vegetative growth during that season (Figure 4.2).

Pod length showed no significant ($P \geq 0.05$) differences among the five pigeonpea varieties; however, cropping systems ($P < 0.05$) and seasons significantly ($P \leq 0.001$) affected pod length across the different varieties (Table 4.8). Longer pods were obtained under strip intercrop plots with a mean of 6.53 cm, while shorter pods were obtained under monocropping and mixed intercropping with a mean of 5.93 cm and 5.97 cm, respectively (Table 4.9). Sharma et al. (2010) who recorded longer pods under intercropping reported similar results. The superior performance of intercrop plots suggests that there was less competition for resources both above ground and below ground. Seasons revealed significant ($P \leq 0.001$) differences regarding pod length, where the longest pod length of 6.60 cm was observed during the 2016/17 season, rather than 5.69 cm, which was observed during the 2015/16 season (Table 4.9).

Table 4.8: Analysis of variance for pod length of five pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	0.16	0.08		
Variety	4	2.18	0.54	2.23	0.1557ns
Error Rep*V	8	2.00	0.24		
Cropping system (CS)	2	6.82	3.41	4.69	0.0214*
V*CS	8	5.96	0.74	1.02	0.4510ns
Error Rep*V*CS	20	14.56	0.73		
Season (S)	1	18.68	18.68	35.02	0.0000**
V*S	4	0.49	0.12	0.23	0.9199ns
CS*S	2	3.49	1.74	3.27	0.0519*
V*CS*S	8	4.84	0.66	1.14	0.3690ns
Error R*V*CS*S	30	16.00	0.53		
Total	89	75.12			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05).

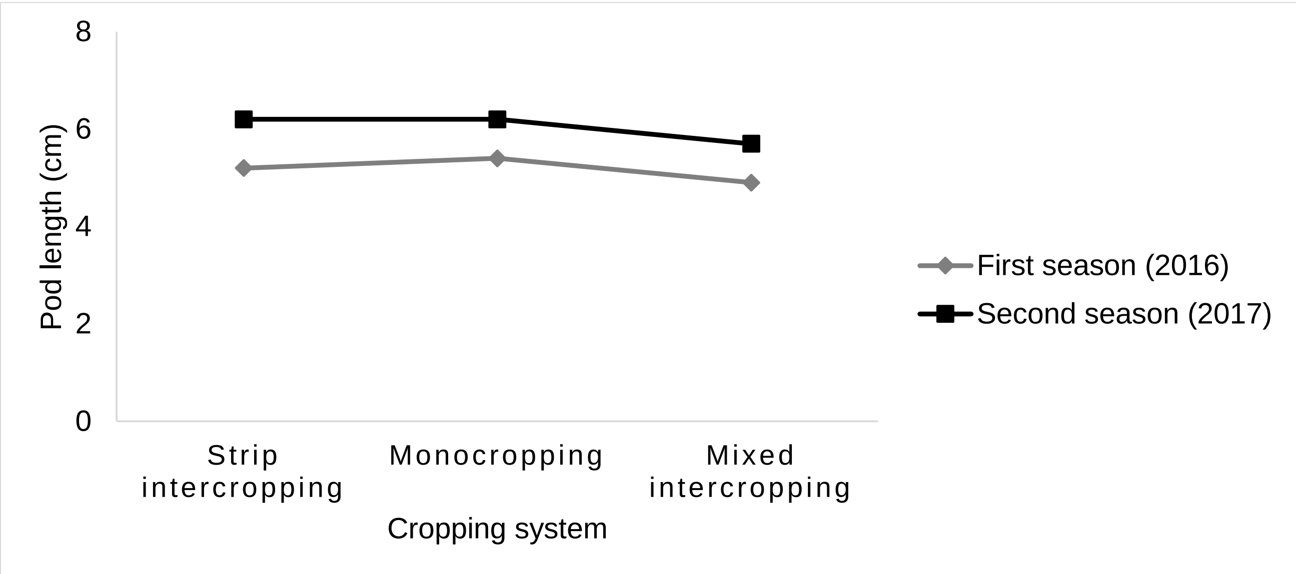

Figure 4.10: Interaction of cropping system x season for pod length during the 2016 and 2017 seasons

Table 4.9: Effect of variety, cropping system and season on yield parameters of pigeonpea during the 2015/16 and 2016/17 seasons

Variety (V)		
	Number of pods per plant	Pod length (cm)
ICEAP 00661	147.28[c]	6.33[a]
ICEAP 87091	142.50[c]	6.33[a]
ICEAP 01101-2	206.61[a]	6.06[a]
ICEAP 00604	157.78[bc]	6.00[a]
ICEAP 001284	197.50[ab]	6.00[a]
Grand mean	170.33	6.14
SEM	20.806	0.1648
Cropping system (CS)		
Monocropping	192.83[a]	5.93[b]
Strip Intercropping	208.37[a]	6.53[a]
Mixed intercropping	109.80[b]	5.97[b]
SEM	8.7019	0.2203
Season (S)		
2015/16	208.53[a]	5.69[b]
2016/17	132.13[b]	6.60[a]
SEM	7.9120	0.1540

Means followed by the same letter in each column do not differ significantly at $P \leq 0.05$. SEM = Standard error of means

4.2.7 Number of seeds per pod

There were no significant ($P \geq 0.05$) differences in the interaction between variety x cropping system x season (V x CS x S) (Table 4.10). The results also revealed no significant ($P \geq 0.05$) differences regarding the number of seeds per pod among the different pigeonpea varieties (Table 4.10). Similar findings were observed by Ojwang *et al.* (2016) who reported no significant differences regarding the number of seeds per pod among pigeonpea genotypes. Cropping systems and seasons showed no significant ($P \geq 0.05$) differences on the number of seeds per pod (Table 4.10). This is expected since the varieties did not differ in pod length.

Table 4.10: Analysis of variance for number of seeds per pod in five pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	0.29	0.14		
Variety (V)	4	0.82	0.21	0.96	0.4783ns
Error Rep*V	8	1.71	0.21		
Cropping system (CS)	2	1.69	0.84	7.24	0.0643ns
V*CS	8	1.98	0.12	1.05	0.4353ns
Error Rep*V*CS	20	2.33	0.12		
Season (S)	1	1.60	1.60	4.36	0.0653ns
V*S	4	0.07	0.02	0.05	0.9959ns
CS*S	2	1.87	0.93	2.55	0.0953ns
V*CS*S	8	1.47	0.18	0.50	0.8464ns
Error R*V*CS*S	30	11.00	0.37		
Total	89	23.82			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, and ns = Not significant

4.2.8 Hundred seed weight (g)

There were no significant (P ≥ 0.05) differences in the interaction between variety x cropping system x season (V x CS x S) (Table 4.11). There were no significant (P ≥ 0.05) differences among pigeonpea varieties on 100 seed mass (Table 4.11). Similarly, cropping systems showed no significant (P ≥ 0.05) differences (Table 4.11). However, significant (P ≤ 0.001) differences were observed for seasons, where the higher seed weight of 13.04 g was recorded during the 2016/17 season and the lower weight was recorded during the 2015/16 season, with a mean of 10.25 g (Table 4.13).

Table 4.11: Analysis of variance for hundred seed weight of five pigeonpea varieties during the 2016 and 2017 seasons

Source of Variation	DF	SS	MS	F	P
Replication (Rep)	2	2.65	1.33		
Varieties (V)	4	4.99	1.25	0.77	0.5746ns
Error Rep*V	8	12.97	1.62		
Cropping system (CS)	2	3.06	1.53	2.65	0.0950ns
V*CS	8	4.31	0.54	0.94	0.5092ns
Error R*V*CS	20	11.52	0.58		
Season (S)	1	174.17	174.17	88.84	0.0000**
V*S	4	5.53	1.38	0.71	0.5947ns
CS*S	2	12.7	6.35	3.24	0.0573ns
V*CS*S	8	3.61	0.45	0.23	0.9823ns
Error R*V*CS*S	30	58.82	1.96		
Total	89	294.308			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

4.2.9 Grain yields (kg ha^{-1})

The interaction between variety x cropping system (V x CS) showed significant ($P \leq 0.0001$) differences on grain yield of pigeonpea varieties (Table 4.12). The top yielding pigeonpea varieties under strip intercropping were ICEAP 01101-2 (1913 kg ha^{-1}), ICEAP 001284 (1890 kg ha^{-1}) and ICEAP 00604 (1118 kg ha^{-1}) (Figure 4.11). Similarly, results were achieved under monocropping.Three varieties outperformed other varieties with mean grain yields of 745 kg ha^{-1} (ICEAP 01101-2), 645.40 kg ha^{-1} (ICEAP 001284) and 665 kg ha^{-1} (ICEAP 00604). The remaining two varieties (ICEAP 87091 and ICEAP 00661) under monocropping and strip intercropping yielded below 600 kg ha^{-1} (Figure 4.11). Differences in yields among pigeonpea varieties were probably due to genetic variations of the varieties which could be linked to their variations in the number of pods. Similar significant variations in pigeonpea varieties for different yield-attributing traits had also been reported in previous studies (Manivel *et al.,* 2012). Most of the studied varieties yielded between 600- 2000 kg ha^{-1} under strip intercropping as compared to mixed intercropping, which produced of between 500-700 kg ha^{-1} (Figure 4.11). The superior performance of varieties under strip intercropping suggests low competition for growth factors and better utilisation of resources. Sharma *et al*. (2010) carried out a field experiment on pigeonpea-based intercropping systems. Their results revealed that pigeonpea intercropping recorded significantly higher pods per plant, seeds per pod and seed yield. Marer *et al*. (2007) also reported that large yield advantage in an intercropping system was due to the component crops that differ in their use of natural resources and utilization was more efficient, resulting in higher yields per unit area than those produced by their sole crops.

The interaction between variety x season (V x S) also showed significant ($P \leq 0.05$) differences, where most of the varieties yielded higher during the 2015/16 than the 2016/17 seasons (Figure 4.12). The increase in yields was attributed to a higher number of branches (16.62) and pods per plant (208.53 pods) during the 2015/16 season, which were enhanced by better rainfall distribution. This is in line with the findings by Egde and Vange (2008) who observed a positive correlation between the number of branches (16), number of pods per plant (210) and yields (1920 kg ha^{-1}). The top three yielders during the 2015/16 season were ICEAP 01101-2, ICEAP 001284 and ICEAP 00604 with grain yields of 1555 kg ha^{-1}, 1280 kg ha^{-1} and 805 kg ha^{-1}, respectively. Furthermore, varieties that obtained high yields during the 2016/17 season were ICEAP 01101-2 (912 kg ha^{-1}) and ICEAP 001284 (937 kg ha^{-1}) (Figure 4.12). This suggests that different pigeonpea varieties may produce a varying range of grain yields, depending on the seasons as influenced by environmental factors (temperature and rainfall) and genetic makeup. A similar observation was made by Zerihun (2016) who reported that significant differences in grain yields were due to environmental variability and genetic factors. The interaction between cropping system x season (CS x S) also showed significant ($P \leq 0.05$) differences, where most of the varieties performed better under strip intercropping during the first season than during the second season, with yields of more than 1000 kg ha^{-1} as compared to mixed intercropping, which had grain yields of below 700 kg ha^{-1} (Figure 4.13).

There were significant ($P \leq 0.05$) yield differences observed among pigeonpea varieties (Table 4.12). The top two varieties were ICEAP 01101-2 (1233 kg ha^{-1}) and ICEAP 001284 (1108 kg ha^{-1}), whereas the low-yielding varieties were ICEAP 00604, ICEAP 87091 and ICEAP 00661 with average yields of below 700 kg ha^{-1} (Table 4.13). Differences in grain yields observed may be attributed to genetic makeup. This agrees with previous findings of Cheboi *et al.* (2016) who recorded differences among pigeonpea due to genetic variation. The reason why two varieties had high yields might be that they are indeterminate cultivars, giving rise to two harvesting peaks. Grain yields were significantly (P ≤ 0.05) affected by cropping systems and seasons. The highest grain yield of 1247 kg ha^{-1} was recorded for strip intercropping as compared to 637 kg ha^{-1} for mixed intercropping (Table 4.13). The decline in grain yield under mixed intercropping compared to strip intercropping might have been the result of intra-species competition for plant growth resources.

Seasons revealed significant (P ≤ 0.05) differences, when higher grain yields of 939 kg ha^{-1} were recorded during 2015/16 than the 641 kg ha^{-1} during the 2016/17 season (Table 4.13). The reduction in yield that was observed during the 2016/17 season was probably due to the low rainfall during the vegetative stage (March 23.12 mm), which must have caused a reduction in yield and yield components (Figure 4.2). This result confirms previous findings of Sarika *et al*. (2013) who reported that low rainfall during the vegetative stage causes the reduction of flowering, pods per plant, seeds per pod and yields in pigeonpea.

Table: 4.12: Analysis of variance for grain yield on pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	2922812	1461406		
Varieties (V)	4	9385113	2346278	18.90	0.0004**
Error Rep*V	8	992915	124114		
Cropping system (CS)	2	2.019E+07	1.009E+07	62.60	0.0000**
V*CS	8	5111070	638884	3.96	0.0059**
Error Rep*V*CS	20	3225282	161264		
Season (S)	1	2003204	2003204	38.81	0.0000**
V*S	4	847074	211768	4.10	0.0091**
CS*S	2	784205	392102	7.60	0.0021**
V*CS*S	8	480838	60104.8	1.16	0.3520ns
Error Rep*V*CS*S	30	1548302	51610.1		
Total	89	4.749E+07			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.0001)

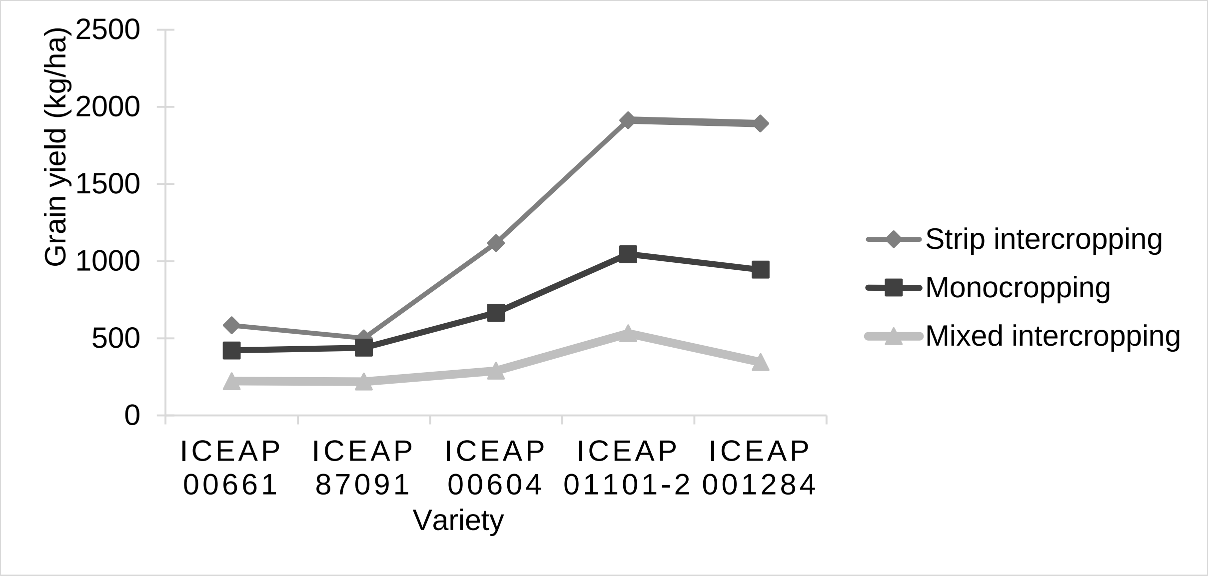

Figure 4.11: Interaction of variety x cropping system for pigeonpea grain yield in the 2016 and 2017 seasons

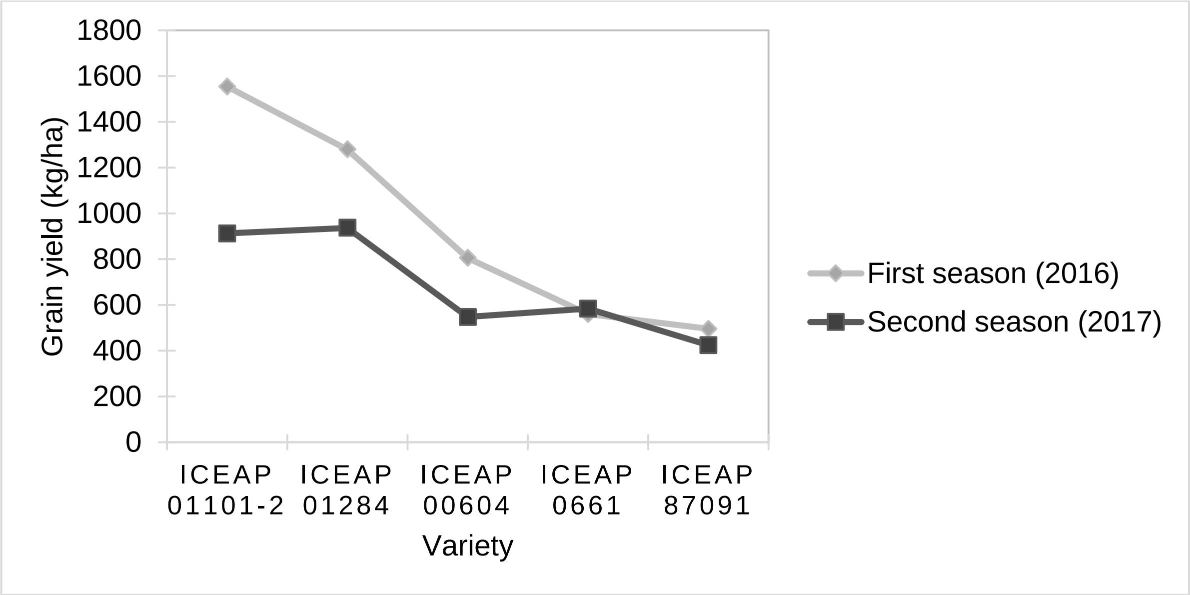

Figure 4.12: Interaction of variety x season for pigeonpea grain yield in the 2016 and 2017 seasons

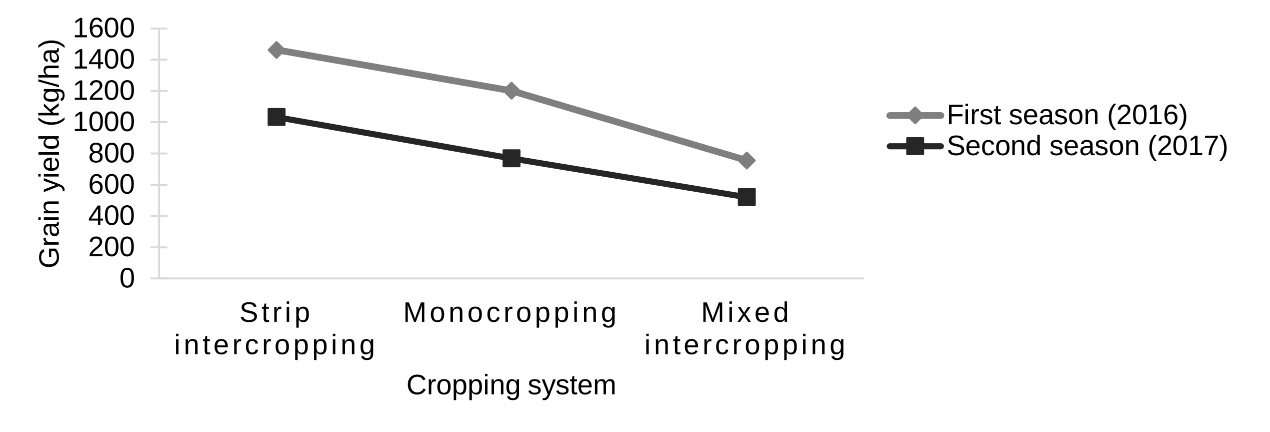

Figure 4:13: Interaction of cropping system x season for pigeonpea grain yields during the 2016 and 2017 seasons

Table 4.13: Effect of variety, cropping system and season on yield parameters of pigeonpea during the 2015/16 and 2016/17 seasons

Variety (V)	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg ha^{-1})
ICEAP 00661	5.17^a	11.89^a	471^b
ICEAP 87091	5.22^a	11.37^a	460^b
ICEAP 01101-2	5.11^a	11.67^a	1233^a
ICEAP 00604	5.28^a	11.40^a	676^b
ICEAP 001284	5.00^a	12.00^a	1108^a
Grand mean	5.16	11.65	790
SEM	0.1542	0.4245	117.43
Cropping system (CS)			
Monocropping	5.13^a	11.78 ^{a}	985^b
Strip Intercropping	5.33^a	11.78 ^{a}	1247^a
Mixed intercropping	5.00^a	11.39 ^{a}	637^c
SEM	0.0882	0.1959	103.69
Season (S)			
2015/16	5.29^a	10.25^b	939^a
2016/17	5.02^a	13.04^a	641 ^{b}
SEM	0.1277	0.2952	47.893

Means followed by the same letter in each column do not differ significantly at P ≤ 0.05. SEM = Standard error of means

4.3 Performance of Maize at the University of Limpopo Experimental Farm (UL Farm)

4.3.1 Number of days to 50% tasselling

The interaction between cropping system x season (CS x S) showed significant differences regarding the number of days to 50% tasselling (Table 4.14). Maize planted during the 2015/16 season under all cropping systems tasselled earlier than during the 2016/17 season, which had mean days that ranged between 72-74 days and 75-78 days during 2015/16 and 2016/17, respectively (Figure 4.14). Late tasselling during the 2016/17 season was probably due to low rainfall (March 23.12 mm) during the reproductive phase, which led to delayed tasselling (Figure 4.2). This agrees with the findings of Otegui and Slafer (2004) who reported that water stress during the reproductive phase delays tasselling and silk emergence relative to pollen shed. Data regarding days to 50% tasselling was not statistically significant ($P \geq 0.05$) under different cropping systems (Table 4.16).

Table 4.14: Analysis of variance for number of days to 50% tasselling of maize during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	279.82	139.91		
Cropping system (CS)	2	90.96	45.48	1.48	0.3306ns
Error Rep *CS	4	123.04	30.76		
Season (S)	1	1690.00	1690.00	602.65	0.0000**
CS*S	2	154.07	77.03	27.47	0.0000**
Error	78	218.73	2.80		
Total	89	2556.62			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

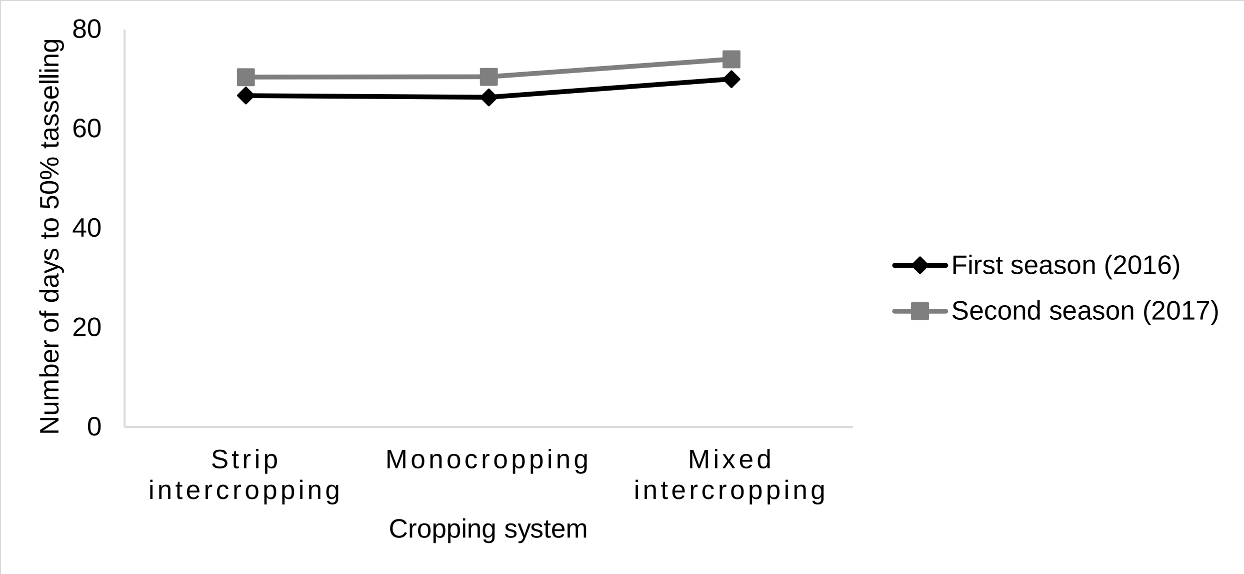

Figure 4.14 Interaction of cropping system x season for number of days to 50% tasselling during the 2016 and 2017 seasons

4.3.2 Number of days to 50% silking

The interaction between cropping system x season (CS x S) showed significant differences regarding the number of days to 50% silking (Table 4.15). During the 2015/16 season, the number of days to 50% silking under all cropping systems was not significantly different. However, mixed intercropping during the 2016/17 season resulted in the highest number of days of 89.33 as compared to monocropping and strip intercropping, which recorded 84.40 and 84.53 days, respectively (Figure 4.15). The highest number of days recorded under mixed intercropping was probably due to high competition for growth factors, which hindered the phenological development of maize.

Seasons revealed significant ($P \leq 0.05$) differences regarding the number of days to reach 50% silking (Table 4.15). Maize planted during the 2015/16 season attained 50% silking earlier at 72.09 days compared to 83.13 days during the 2016/17 season (83.18 days) (Table 4.16). The maximum number of days to 50% silking during the 2016/17 season at the UL Farm was attributed due to low rainfall (March 23.12 mm) during the reproductive phase (Figure 4.2). This agrees with the findings of Otegui and Slafer (2004) who reported that water stress during the reproductive phase delays tasselling and silk emergence relative to pollen shed.

Table 4.15: Analysis of variance for number of days to 50% silking of maize intercropped with pigeonpea during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	90.42	45.21		
Cropping system (CS)	2	14.29	7.14	0.59	0.5945ns
Error Rep *CS	4	48.11	12.03		
Season (S)	1	217.78	217.78	73.26	0.0000**
CS*S	2	42.16	21.08	7.09	0.0015**
Error	78	231.87	3.00		
Total	89	644.62			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

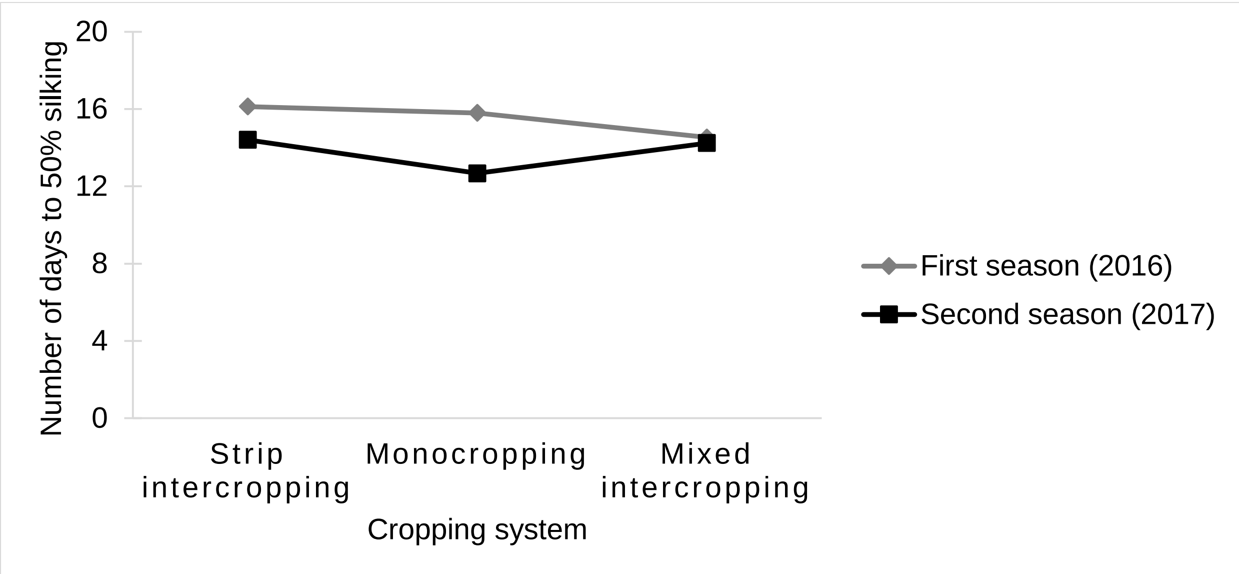

Figure 4.15: Interaction of cropping system x season for the number of days to 50% silking in the 2016 and 2017 seasons

Table 4.16: Effect of cropping system and season on phenological development of maize intercropped with pigeonpea during the 2015/16 and 2016/17 seasons

Cropping system (CS)	Number of days to 50% tasselling	Number of days to 50% silking
Monocropping	72.00[a]	76.97[b]
Strip Intercropping	68.63[b]	76.43[b]
Mixed intercropping	68.40[b]	79.50[a]
SEM	0.3426	0.3232
Season (S)		
2015/16	67.73[b]	72.09[b]
2016/17	71.62[a]	83.18[a]
SEM	0.2427	0.1970

Means followed by the same letter in each column do not differ significantly at P ≤ 0.05. SEM = Standard error of means

4.3.3 Plant height (cm)

The interaction between cropping system x season (CS x S) revealed significant (P ≤ 0.05) differences (Table 4.17). Strip intercropping during the 2015/16 season produced taller plants of 146.60 cm. This was significantly higher than mixed intercropping and monocropping, which had 118.00 cm and 135.13 cm, respectively (Figure 4.16). Taller plants observed under strip intercropping was probably due to low competition for growth factors (nutrients, light and water). During the 2016/17 season, plant height did not show differences in all cropping systems, meaning that maize plants responded the same way (Figure 4.16).

Cropping systems significantly (P ≤ 0.05) affected maize plant height (Table 4.17). The mean plant height of maize in strip intercropping and monocropping systems gave the tallest plants of 140.83 cm and 134.57 cm, respectively when compared to mixed intercropping, which gave the shortest plant height of 110.17 cm (Table 4.19). There was significant (P ≤ 0.05) difference in the mean plant height as influenced by both seasons (Table 4.19). Season 2016/17 produced taller plants of 133.24 cm as compared to 124.80 cm during the 2015/16 season (Table 4.19). The generally taller plants during the 2016/17 season may be attributable to higher temperatures and rainfall effects. This agrees with findings of Mostafavi *et al*. (2011) who reported tall maize plants due to adequate rainfall during anthesis.

Table 4.17: Analysis of variance for maize plant height during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	593.1	296.6		
Cropping system (CS)	2	33549.0	16774.5	34.86	0.0029**
Error Rep *CS	4	1924.7	481.2		
Season (S)	1	2901.0	2901.0	10.94	0.0014**
CS*S	2	14924.3	7462.2	28.13	0.0000**
Error	78	20692.4	265.3		
Total	89	74584.5			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and * Significant at ($P \leq 0.05$)

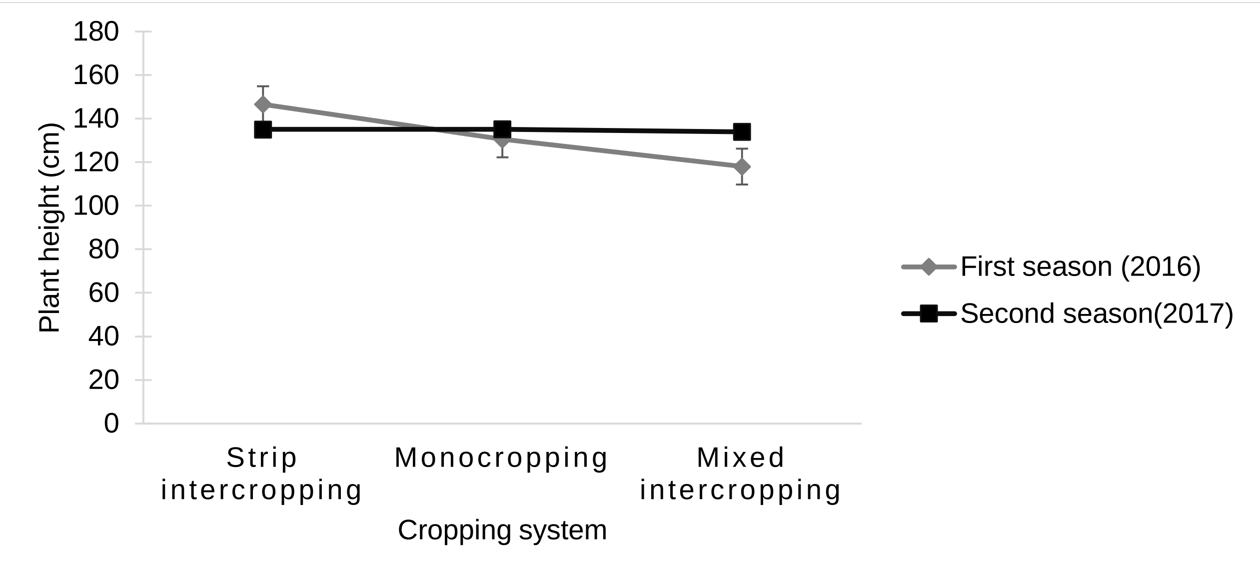

Figure 4.16: Interaction of cropping system x season for plant height during the 2016 and 2017 seasons

4.3.4 Number of cobs per plant

The interaction between cropping system x season (CS x S) showed no significant ($P \leq 0.05$) differences. Similarly, there were no significant ($P \geq 0.05$) differences with respect to the number of cobs per plant under different cropping systems (Table 4.18). However, the number of cobs per plant was significantly ($P \leq 0.05$) affected by seasons

(Table 4.18). A higher number of cobs per plant of 1.58 was observed during 2015/16 season as compared to 1.29 during 2016/17 (Table 4.19). The reduced number of cobs per plant observed for the 2016/17 season was probably due to lower rainfall that occurred during the tasselling stage (Figure 4.20). This agrees with what was reported by Osborne *et al.* (2002) who stated that water stress occurring prior to silking, significantly reduces the number of kernels per plant. The results also show that the maize cultivar used, PAN 6479, and has a strong trait for prolificacy.

Table 4.18: Analysis of variance for number of cobs per plant during the 2016 and 2017 season

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	2.82	1.41		
Cropping system (CS)	2	1.09	0.54	0.49	0.6452ns
Error Rep *CS	4	4.44	1.11		
Season (S)	1	1.88	1.88	6.12	0.0155*
CS*S	2	1.49	0.74	2.43	0.0950ns
Error	78	23.93	0.31		
Total	89				

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

Table 4.19: Effect of cropping system and season on phenological development of maize during the 2015/16 and 2016/17 seasons

Cropping system (CS)		
	Plant height (cm)	Number of cob per plant
Monocropping	134.57^{a}	$1.47^{a\,b}$
Strip Intercropping	140.83^{a}	1.70^{a}
Mixed intercropping	110.17^{b}	1.13^{b}
SEM	1.6507	0.1453
	Season (S)	
2015/16	133.24^{a}	1.58^{a}
2016/17	123.80^{b}	1.29^{b}
SEM	2.4932	0.1035

Means followed by the same letter in each column do not differ significantly at $P \leq 0.05$. SEM = Standard error of means

4.3.5 Cob length (cm)

The interaction between cropping system x season (CS x S) showed significant differences ($P \leq 0.05$) on maize cob length (Table 4.20). During the 2015/16 season, maize produced longer cobs of 16 cm under strip intercropping and monocropping as compared to mixed intercropping, which produced shorter cobs of 14 cm (Figure 4.17). Cob length produced during the 2016/17 season did not differ significantly under the three cropping systems (Figure 4.17). However, significant ($P \leq 0.05$) differences were observed for cob length as influenced by different cropping systems and seasons (Table 4.20). Longer cobs of 15.27 cm and 15.17 cm, respectively, were recorded under strip intercropping and monocropping, as compared to 13.50 cm, which was observed under mixed intercropping (Table 4.23). This was probably due to low competition for growth factors. Seasons revealed significant ($P \leq 0.05$) differences in cob length, where a long cob of 15.42 cm was observed during the 2015/16 season, compared to 13.87 cm, which was observed during the 2016/17 season (Table 4.23). Reduced cob length observed for the 2016/17 season was probably due to lower rainfall during the anthesis stage (Figure 4.20). This agrees with what was reported by Mostafavi *et al*. (2011) who stated that pre-anthesis drought significantly reduces kernel length.

Table 4.20: Analysis of variance for maize cob length during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	62.513	31.257		
Cropping system (CS)	2	247.787	123.894	8.71	0.0349**
Error Rep *CS	4	56.878	14.219		
Season (S)	1	62.250	62.250	20.21	0.0000**
CS*S	2	235.327	117.664	38.20	0.0000**
Error	78	240.240	3.080		
Total	89	904.995			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and * Significant at ($P \leq 0.05$)

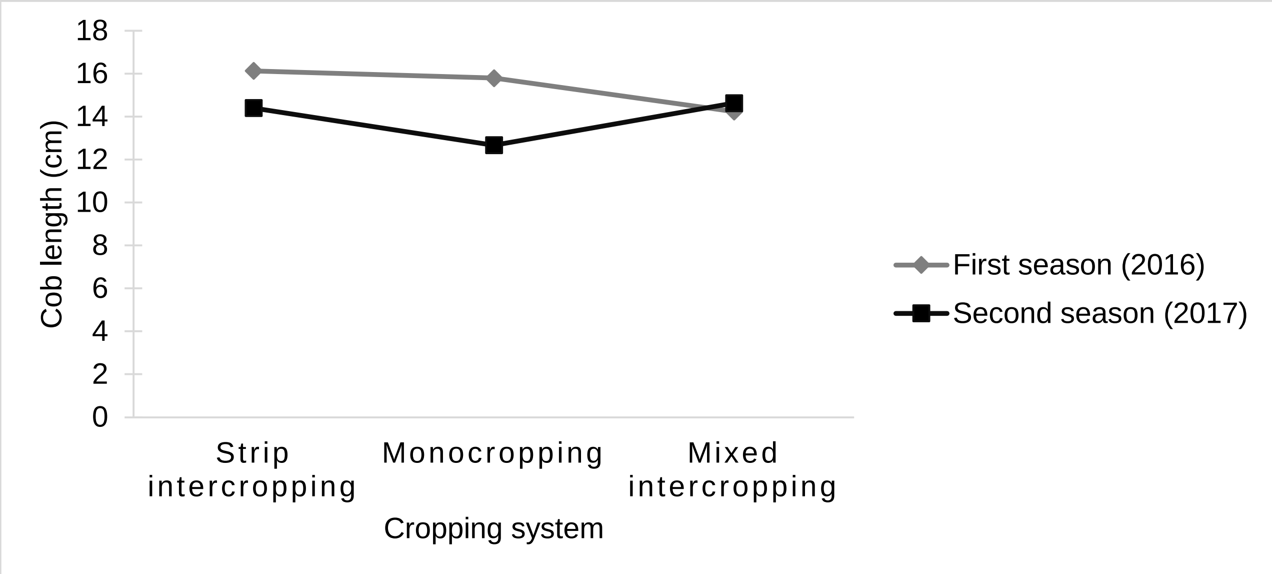

Figure 4.17: Interaction of cropping system x season for maize cob length in the 2016 and 2017 seasons

4.3.6 Grain yield (kg ha^{-1})

The interaction between cropping system x season (CS x S) was not significant for maize grain yield (Table 4.21). However, maize grain yield was significantly ($P \leq 0.05$) affected by cropping systems, where the highest grain yield of 1 794 kg/ha was recorded under monocropping, followed by strip intercropping (1597 kg ha^{-1}), and the lowest grain yield of 921 kg ha^{-1} for mixed intercropping (Table 4.23). This result agrees with previous findings by Mashingaidze *et al*. (2006) who reported that monocropping (6 t ha^{-1}) maize had significantly higher yields than intercropped (5 ha^{-1}) maize. This is also supported by Teshome *et al. (*2015) who report that sole cropped maize has significantly higher grain yield (7.33 t ha^{-1}) than the intercropped system (7.01 t ha^{-1}).

Seasons showed significant differences, when the highest grain yield of 1450 kg ha^{-1} was recorded during the 2015/16 season rather than the 958 kg ha^{-1} yield during the 2016/17 season (Table 4.23). The reduced rainfall probably caused this during the tasselling stage. This was supported by the work done by Katsaruware and Manyanhaire (2009) who stated that higher maize yields during their first season (2005/06) could be attributed to higher temperatures and rainfall effects.

Table 4.21: Analysis of variance for maize grain yields during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	3731240	1865620		
Cropping system (CS)	2	2.815E+07	1.407E+07	23.99	0.0059*
Error Rep*CS	4	2347039	586760		
Season (S)	1	1918636	1918636	2.41	0.1243ns
CS*S	2	1860885	930442	1.17	0.3156ns
Error	78	6.201E+07	794956		
Total	89				

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * significant at ($P \leq 0.05$)

4.3.7 Maize stover (kg ha^{-1})

The interaction of cropping system x season (CS x S) showed no significant differences for maize stover (Table 4.22). Maize stover was affected by cropping systems and seasons (Table 4.22). A high stover yield of 2 107 kg/ha was recorded under monocropping followed by strip intercropping (1380 kg ha^{-1}), and a lower stover of 856.20 kg ha^{-1} was recorded under mixed intercropping (Table 4.23). This result confirms previous findings of Teshome *et al. (*2015) who reported that the cropping system had a highly significant effect on maize biomass, where higher biomass of maize (19 t ha^{-1}) was produced from sole-cropped maize compared to that of intercropped maize with soybean (17 t ha^{-1}). Reduction in stover under mixed intercropping plots has been attributed to high competition for plant growth resources. The highest stover of 2053 kg ha^{-1} was recorded during the 2015/16 season as compared to 1009 kg ha^{-1} recorded for the 2016/17 season. This agrees with previous findings of Katsaruware and Manyanhaire (2009) who reported that high stover yields (16 t ha^{-1}) during the first season of their research could be attributed to higher temperatures and rainfall effects.

Table 4.22: Analysis of variance for maize stover during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	2133377	2091688		
Cropping system (CS)	2	8,32E+07	4,16E+07	58.79	0.0011*
Error Rep*CS	4	2831075	707769		
Season (S)	1	6639438	6639438	4.06	0.0074*
CS*S	2	9927288	4963644	3.03	0.1638ns
Error	78	1,28E+08	1635762		
Total	89	3264543			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

Table 4.23: Some yield parameters of maize influenced by cropping systems during the 2015/16 and 2016/17 seasons

Cropping system (CS)	Cob length (cm)	Grain yield (kg/ha)	Stover yield (kg/ha)
Monocropping	15.17[a]	1794.20[a]	2107b
Strip Intercropping	15.27[a]	1597.60[a]	1380a
Mixed intercropping	13.50[b]	921.70[b]	856[c]
SEM	0.4757	187.97	217.59
Season (S)			
2015/16	15.42[a]	1450.50[a]	2053[a]
2016/17	13.87[b]	958.50[b]	1009[b]
SEM	0.2771	197.78	212.60

Means followed by the same letter in each column does not differ significantly at P ≤ 0.05. SEM = Standard error of means

4.4 Assessment of Intercropping Productivity

4.4.1 Land Equivalent Ratio (LER)

The Land Equivalent Ratio (LER) during both seasons under strip intercropping ranged from 1.58 to 2.40, whereas under mixed intercropping, it ranged between 0.12 and 1.83 during both seasons (Table 4.24). LER ranged from 1.58-2.40 in maize-pigeonpea intercrop system, indicating that intercrops are more productive than a sole crop. This may have resulted from complementary and efficient use of growth resources. The lower LER under mixed intercropping can be explained by the findings of Ofori and Stern 1987 who reported that light is the most important factor determining LER of intercropping, and LER declines when legumes become severely shaded.

The mean for LER in both seasons was greater than 1; therefore, strip intercropping had a yield advantage over mixed intercropping (Table 4.24). Willey (2006) reported that LER ≥ 1 implies intercropping is advantageous and there is better use of growth resources because of the complementary effect between component crops, which is considered as a major source of yield advantages from intercropping. Ullah *et al.* (2007) reported the total LER for yield ranged between 1.06 and 1.58. This showed yield and growth advantages of intercropping. Similar LER values greater than 1.0 in maize/pigeonpea intercropping had been reported by Egbe and Adeyemo (2006), Smith *et. al.* (2001). The LER values above 1 under strip intercropping during both seasons could be attributed to good compatibility of pigeonpea varieties with maize.

Table 4.24: Partial and total LER for the component crops under strip intercropping and mixed intercropping during the 2016 and 2017 seasons

2015/16 season						
	Strip intercropping			Mixed intercropping		
Crop mixture	PLER $_{maize}$	PLER$_{pigeonpea}$	LER $_{total}$	PLER$_{maize}$	PLER$_{pigeonpea}$	LER $_{total}$
ICEAP 001284 +Maize	1.30	1.10	2.40	0.69	1.14	1.83
ICEAP 00604 +Maize	1.13	1.18	2.31	0.18	0.16	0.34
ICEAP 00661 +Maize	1.06	0.90	1.96	0.24	0.20	0.44
ICEAP 01101-2 +Maize	0.80	0.78	1.58	0.84	0.81	1.65
ICEAP 87091 +Maize	1.01	1.08	2.09	0.26	0.30	0.56
Mean	1.06[a]	1.01[a]	2.07[a]	0.44[a]	0.52[a]	0.96[a]
P-level	0.7431	0.0472	0.0411	0.5021	0.6439	0.6859
2016/17 season						
	Strip intercropping			Mixed intercropping		
Crop mixture	PLER $_{maize}$	PLER$_{pigeonpea}$	LER$_T$	PLER $_{maize}$	PLER $_{pigeonpea}$	LER$_T$
ICEAP 001284 +Maize	1.12	1.19	2.31	0.12	0.10	0.22
ICEAP 00604 +Maize	1.30	1.10	2.40	0.19	0.15	0.34
ICEAP 00661 +Maize	1.03	1.00	2.03	0.25	0.29	0.54
ICEAP 01101-2 +Maize	0.86	1.12	1.98	0.08	0.04	0.12
ICEAP 87091 +Maize	0.97	1.07	2.04	0.11	0.10	0.21
Mean	1.06[a]	1.10[a]	2.16[a]	0.15[a]	0.14[a]	0.29[a]
	0.2310	0.0451	0.0142	0.3452	0.1065	0.2867

PLER = partial Land Equivalent Ratio and LER$_T$ = total Land Equivalent Ratio

4.5 Weather Results during 2015/16 and 2016/17 Seasons at Ga-Thaba Village

The first trial was planted on 14 January 2016. During the first season, there was a little bit of rainfall in January and February with an average of 0.57-0.74 mm, coupled with very high temperatures of about 33.87-33.72°C (Figure 4.18). Higher temperatures (33.87-31.74°C) from January to March shorten the period of flowering, whereas a cool day and night due to low temperatures lengthens flowering (Figure 4.18). From March towards the end of the season, rainfall distribution was poor, coupled with a reduction in temperatures (31-23°C), which resulted in a reduction in the number of pods per plant and grain yields during the 2015/16 season (Figure 4.18). The second season was very long, since planting was done on 15 December 2016. Rainfall, especially during December and January 2016/17, was high with an average of 3.08-3.60 mm, coupled with high temperatures (30.84-29.68°C) (Figure 4.19). Adequate rainfall, especially after planting during the months of December and January, promoted crop establishment and reduced crop failure. From March to June during the 2016/17 season, Ga-Thaba experienced very low rainfall of 0-0.75 mm and rain distribution was poor, coupled with very high temperatures of about 24-30°C (Figure 4.19). During the 2015/16 and the 2016/17 seasons at Ga-Thaba, rainfall distribution was not the same, when the total rainfall during the growing period at Ga-Thaba was 1.88 and 7.55 mm, respectively, for 2015/16 and 2016/2017 cropping seasons (Figures 4.18 and 4.19).

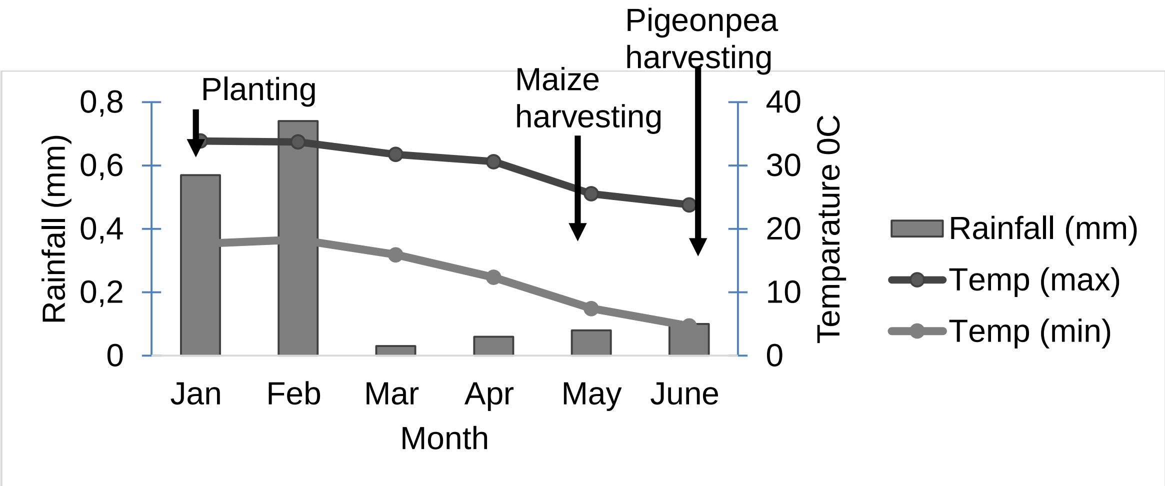

Figure 4.18: Mean monthly rainfall, mean minimum and maximum temperatures during the 2015/16 season at Ga-Thaba
Source: Agricultural Research Council - ISCW and the University of Limpopo Weather Station records

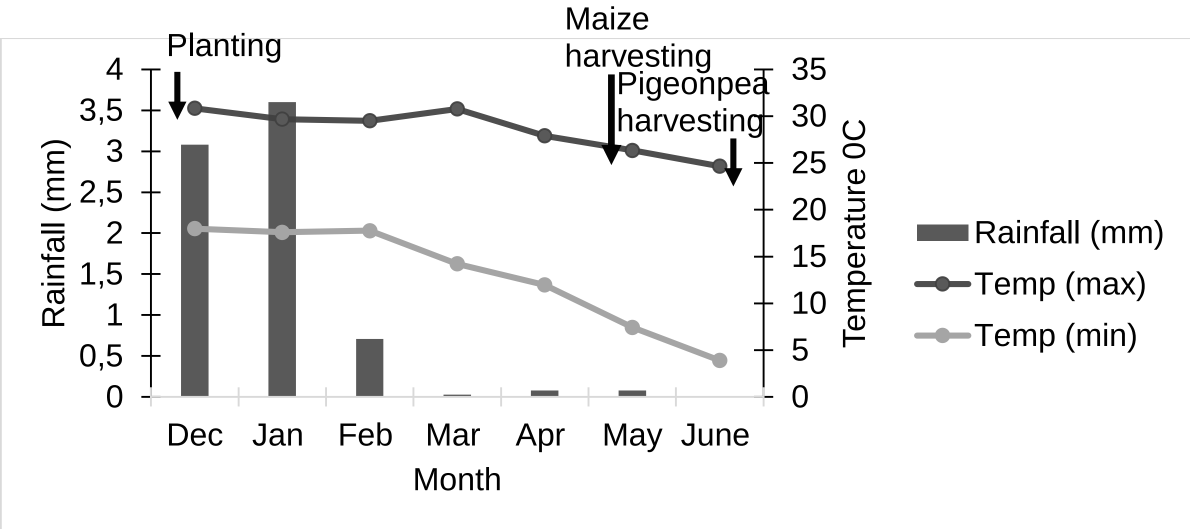

Figure 4.19: Mean monthly rainfall, minimum and maximum temperature during the 2016/17 season at Ga-Thaba
Source: Agricultural Research Council - ISCW and the University of Limpopo Weather Station records

4.6 Performance of Pigeonpea Varieties at Ga-Thaba during the 2015/16 and 2016/17 seasons

4.6.1 Number of days to 50% flowering

The interaction between variety x cropping system x season (V x CS x S) showed significant ($P \leq 0.05$) differences (Table 4.25). During the 2015/16 season, variety ICEAP 00661 reached 50% flowering at 129.33 and 125.00 days, respectively, under monocropping and strip intercropping, and was significantly later than ICEAP 01101-2 and ICEAP 00604, which attained 50% flowering at 119.67 and 107.00 days, respectively, under strip intercropping, whereas in monocropping, it was recorded as ICEAP 01101-2 (126 days) and ICEAP 00604 (110.00 days) (Figure 4.20). The minimum number of days to 50% flowering during the 2015/16 season under strip intercropping was attained by ICEAP 87091 and ICEAP 001284 at 103.67 and 103.33 days, respectively, whereas in monocropping, it was recorded as ICEAP 87091 (106.33) and ICEAP 001284 (105.67) (Figure 4.20).

The highest number of days to 50% flowering during the 2016/17 season under strip intercropping was recorded for ICEAP 01101-2 (108.33 days), followed by ICEAP 87091 (99.00 days) and ICEAP 00661 (97.33 days), whereas the lowest number of days of 94.00 and 88.00 were recorded by ICEAP 00604 and ICEAP 001284, respectively (Figure 4.20). During the 2016/17 season under monocropping, the number of days to 50% flowering was attained by ICEAP 01101-2 (108.67 days), followed by ICEAP 87091 (100.00 days), ICEAP 00604 (98.35 days), ICEAP 00661 (98.33 days) and ICEAP 001284 (88.00 days). During both seasons, pigeonpea varieties under mixed intercropping responded the same way to 50% flowering, which ranged between 106.67 and 107.00 days (Figure 4.20). The differences regarding the number of days to 50% flowering were due to varietal characteristics. This is supported by the work done by Deshmuk and Mate (2013) who reported significant differences among pigeonpea due to genetic variability.

During both seasons at Ga-Thaba, the results revealed that there were significant ($P \leq 0.05$) differences with respect to the number of days to 50% flowering among pigeonpea varieties (Table 4.25). Variety ICEAP 01101-2 attained 50% flowering in 126.39 days, followed by ICEAP 00661 and ICEAP 87091 with 123.50 and 122.06 days, respectively (Table 4.27). ICEAP 00604 and ICEAP 001284 reached the lowest number of days to 50% flowering at 118.61 and 116.44 days, respectively (Table 4.27). The three varieties (ICEAP 01101-2, ICEAP 00661 and ICEAP 87091) flowered relatively late, which was probably because they are indeterminate, while ICEAP 00604 and ICEAP 001284 are determinate. Therefore, they reached 50% flowering earlier. These findings are in close conformity with the findings of Ojwang *et al.* (2016) who observed that a genotype that has a short vegetative growth attains 50% flowering earlier than those do that have long vegetative growth. The number of days to 50% flowering was significantly ($P \leq 0.05$) affected by cropping systems (Table 4.25). The lowest number of days to 50% flowering was observed under strip intercropping (119.60 days), whereas 122.10 and 122.50 days were observed under monocropping and mixed intercropping, respectively (Table 4.27). Both seasons revealed significant ($P \leq 0.05$) differences regarding the number of days to 50% flowering, when 127.60 days was observed for 2016/17 compared to 115.20 days for the 2015/16 season (Table 4.27). The highest number of days observed for 2016/17 might be ascribed to cool temperatures during the day, which were prevalent during the 2016/17 season (Figure 4.18). These findings agree with previous findings of Silim *et al. (*2007) who reported that cool temperatures lengthened the flowering time, while elevated temperatures shorten the duration of flowering in pigeonpea.

Table 4.25: Analysis of variance for number of days to 50% flowering during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	0.47	0.23		
Variety (V)	4	1117.16	279.29	34.74	0.0000**
Error Rep*V	8	64.31	8.04		
Cropping system (CS)	2	148.20	74.10	16.37	0.0001**
V*CS	8	642.91	80.36	17.75	0.0000**
Error Rep*V*CS	20	90.56	4.53		
Season (S)	1	3459.60	3459.60	1044.85	0.0000**
V*S	4	211.29	52.82	15.95	0.0000**
CS*S	2	2460.20	1230.10	371.51	0.0000**
V*CS*S	8	167.58	20.95	6.33	0.0001**
Error R*V*CS*S	30	99.33	3.31		
Total	89	8461.60			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and * Significant at (P ≤ 0.05)

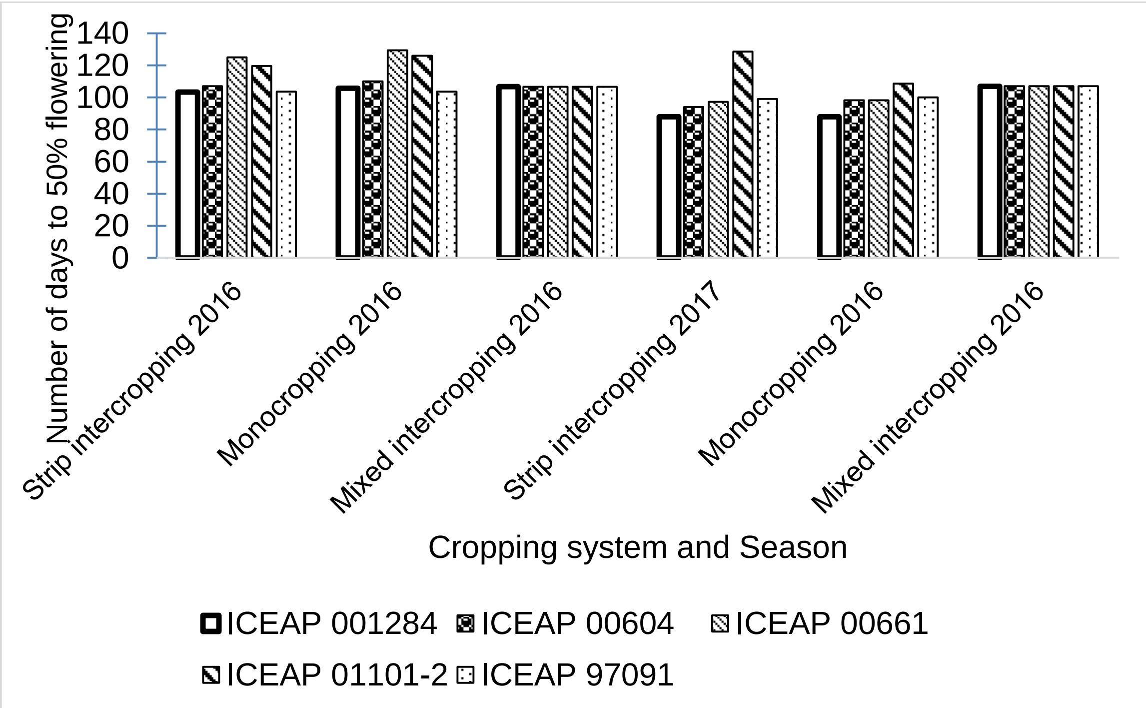

Figure 4.20: Interaction of variety x cropping system x season for number of days to 50% flowering in the 2016 and 2017 seasons

4.6.2 Number of days to 90% physiological maturity

Physiological maturity of pigeonpea was significantly ($P \leq 0.05$) affected by the interaction between variety x cropping system (V x CS) (Table 4.26). Pigeonpea varieties under mixed intercropping had the highest number of days to 90% physiological maturity, significantly higher than all varieties under strip intercropping and monocropping (Figure 4.21). Varieties (ICEAP 01101-2 and ICEAP 87091) needed the highest number of days (202.00 and 199.00 days, respectively) to attain 90% physiological maturity under strip intercropping, and 201.17 and 193.00 days, respectively, for monocropping (Figure 4.21). The shortest period, being the lowest number of days to 90% physiological maturity under strip intercropping was observed for ICEAP 00661 (192.33 days), ICEAP 00604 (186.00 days) and ICEAP 001284 (173.83 days), while under monocropping, it was observed for ICEAP 00661 (190.17 days), ICEAP 00604 (186.00 days) and ICEAP 001284 (179.17 days) (Figure 4.21). Grain legumes such as pigeonpea are perennial in nature, and as long as there is available moisture, such moisture can increase or extend the time taking until maturity of some of the varieties. Variations in number of days to 90% physiological maturity on varieties under the cropping systems were probably due to genetic characteristics of the varieties. These findings agree with previous findings of Deshmuk and Mate (2013) who reported variations in the number of days to 90% physiological maturity among pigeonpea varieties being due to genetic makeup.

There were some significant ($P \leq 0.05$) differences with respect to the number of days to 90% physiological maturity among pigeonpea varieties (Table 4.26). Differences in physiological maturity observed were also influenced by days to 50% flowering. Hluyako (2015) reported that days to flowering and days to maturity are always related because when the plant flowers early, it is most likely to mature early, if it is a determinate variety. Varieties ICEAP 001284 and ICEAP 00604 exhibited the shortest growth period of 185.22 and 191.56 days, respectively, and were significantly different compared to the other four varieties (Table 4.27). Variety ICEAP 01101-2 had the longest maturity period (201.94 days) and was regarded as a late maturing cultivar when compared to the other four varieties (Table 4.27). Varieties ICEAP 001284 and ICEAP 00604 had the shortest period or number of days to 50% flowering, and attained its physiological maturity earlier, while ICEAP 01101-2 attained its physiological maturity late. This is in line with the findings of Hluyako (2015) who reported that early flowering results in early maturity, whereas late flowering results in late physiological maturity.

Cropping systems showed no significant (P ≥ 0.05) differences among pigeonpea varieties (Table 4.26). However, significant (P ≤ 0.05) differences were observed across seasons (Table 4.26), when the maximum number of days (200.07) was observed during the 2016/17 season, while 188.73 days were observed for the 2015/16 season (Table 4.27). This may be due to the higher temperatures that were observed in the 2015/16 season than in the 2016/17 season. This was supported by Nagraj *et al*. (2016) who indicated that temperatures have an influence on maturity of pigeonpea, where low temperatures extend the time to maturity, while high temperatures shorten the duration of pigeonpea maturity.

Table 4.26: Analysis of variance for number of days to 90% physiological maturity during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	37.8	18.90		
Variety (V)	4	2879.0	719.76	26.65	0.0001**
Error Rep*V	8	216.1	27.01		
Cropping system (CS)	2	3083.3	1541.63	52.94	0.5031ns
V*CS	8	1764.0	220.49	7.57	0.0001**
Error Rep*V*CS	20	582.4	29.12		
Season (S)	1	2890.0	2890.00	82.60	0.0000**
V*S	4	141.4	35.36	1.01	0.4176ns
CS*S	2	71.7	35.83	1.02	0.3713ns
V*CS*S	8	478.2	59.78	1.71	0.1373ns
Error R*V*CS*S	30	1049.7	34.99		
Total	89	1319.6			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

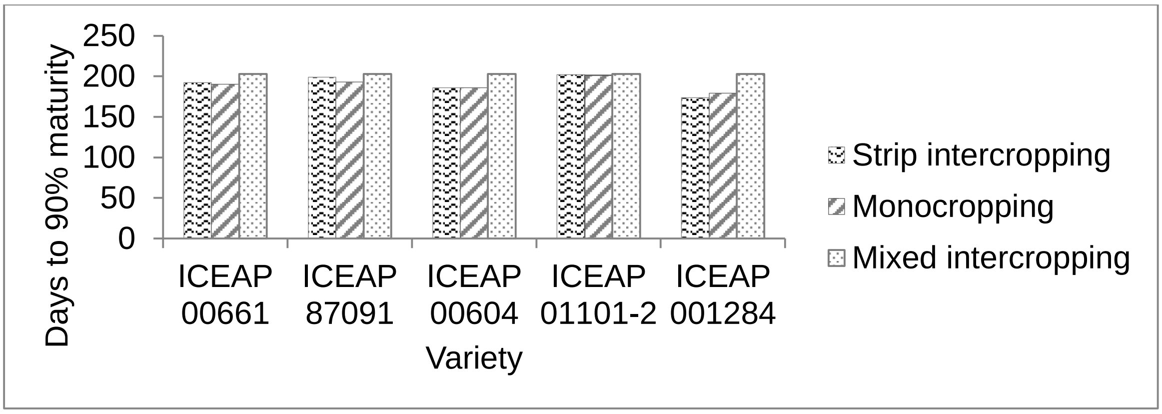

Figure 4.21: Interaction of cropping system x variety for the number of days to 90% physiological maturity in the 2016 and 2017 seasons

Table 4.27: Effect of variety, cropping system and season on phenological development of pigeonpea varieties during the 2015/16 and 2016/17 seasons

Variety (V)	Number of days to 50% flowering	Number of days to 90% maturity	Duration of the reproductive development
ICEAP 00661	123.50^{b}	196.06^{b}	72.60 ^{b}
ICEAP 87091	122.06^{b}	197.22^{a}	75.20 ^{a}
ICEAP 01101-2	126.39^{a}	201.94^{b}	75.60 ^{a}
ICEAP 00604	118.61^{c}	191.56^{c}	72.95 ^{b}
ICEAP 001284	116.44^{c}	185.22^{d}	68.78 ^{c}
Grand mean	121.40	194.40	73.03
SEM	0.9451	1.7324	1.2340
	Cropping system (CS)		
Monocropping	122.10^{a}	189.90^{a}	67.80 ^{b}
Strip intercropping	119.60^{b}	190.63^{a}	71.03 ^{a}
Mixed intercropping	122.50^{a}	192.67^{a}	70.17 ^{a}
SEM	0.5494	1.3934	1.4321
	Season (S)		
2015/16	115.20^{b}	188.73^{b}	73.53 ^{b}
2016/17	127.60^{a}	200.07^{a}	72.40 ^{a}
SEM	0.3836	1.2470	1.6532

Means followed by the same letters in each column do not differ significantly at P ≥ 0.05. SEM = Standard error of means

4.6.3 Number of primary branches

There were no significant (P ≥ 0.05) differences observed on the interaction between variety x cropping system x season (V x CS x S) regarding the number of primary branches (Table 4.28). Pigeonpea varieties showed no significant (P ≥ 0.05) differences for number of primary branches; similarly, cropping systems showed no significant (P ≥ 0.05) differences. However, seasons revealed significant (P ≤ 0.05) differences among the pigeonpea varieties (Table 4.28). The high number of primary branches (9.71) were observed during the 2015/16 season, while in the 2016/17 season, 6.87 were observed (Table 4.30). The high number of primary branches observed were attributed to high rainfall during the 2015/16 season at Ga-Thaba. This agrees with what was reported by Nagraj *et al.* (2016) who stated that adequate rainfall at the critical developmental stage, especially during flowering, promotes a greater number of branches per plant on pigeonpea genotypes.

Table 4.28: Analysis of variance for number of primary branches during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	1.62	0.81		
Variety(V)	4	1.93	0.48	0.26	0.8925ns
Error Rep*V	8	14.60	1.83		
Cropping system (CS)	2	5.76	2.88	3.89	0.0673ns
V*CS	8	8.80	1.10	1.49	0.2230ns
Error Rep*V*CS	20	14.78	0.74		
Season (S)	1	182.04	182.04	117.87	0.0000**
V*S	4	14.51	3.63	2.35	0.0769ns
CS*S	2	3.36	1.68	1.09	0.3504ns
V*CS*S	8	10.76	1.34	0.87	0.5516ns
Error R*V*CS*S	30	46.33	1.54		
Total	89	304.49			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

4.6.4 Plant height (cm)

There were significant ($P \leq 0.05$) differences found regarding the interaction between cropping system x season (CS x S) (Table 4.29). During the 2016/17 season, monocropping produced higher plants of 186.53 cm, which was significantly higher than the 111.33 cm found during the 2015/16 season under monocropping (Figure 4.22). Strip intercropping during both seasons produced taller plants at 130.73 cm and 115.33 cm, respectively during 2015/16 and 2016/17, compared to 100.67 cm and 107.73 cm, which was produced under mixed intercropping during 2015/16 and 2016/17, respectively (Figure 4.22). The superior plant height during 2015/16 was probably due to the higher temperatures during the growing period (Figure 4.18). During the 2015/16 season, Ga-Thaba experienced higher temperatures with a range of 30.61-31.74^{o}C from the vegetative stage until physiological maturity (Figure 4.18). This agrees with previous findings of Silim *et al.* (2007) who reported that plant height in pigeonpea is positively correlated to temperature, whereby under higher temperatures, plants grow taller, while a decrease in temperatures results in a reduction in plant height.

Plant height showed no significant ($P \geq 0.05$) differences among the varieties tested; however, cropping systems and seasons revealed significant differences (Table 4.29). The mean plant height of pigeonpea in monocropping resulted in the tallest height of 158.20 cm compared to strip intercropping and mixed intercropping, which resulted in the shortest plants with a height of 106.47 cm and 104.00 cm, respectively (Table 4.30). Seasons showed significant differences, where taller plants of 134.22 cm height were observed during the 2015/16 rather than 2016/17 season, which had achieved plants with a height of 111.56 cm (Table 4.30). Taller plants during the 2015/16 season were probably due to better rainfall distribution during the vegetative growth. This agrees with what was reported by Nagraj *et al.* (2016) who stated that adequate rainfall at the critical stage of plant development, especially during flowering, results in higher plants of pigeonpea genotypes.

Table 4.29: Analysis of variance for plant height of pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	88	43.8		
Variety (V)	4	527	131.7	1.09	0.4248ns
Error Rep*V	8	971	121.3		
Cropping system (CS)	2	56201	28100.3	372.33	0.0000**
V*CS	8	1112	138.9	1.84	0.1281ns
Error Rep*V*CS	20	1509	75.5		
Season (S)	1	11560	11560.0	169.97	0.0000**
V*S	4	648	161.9	2.38	0.0738ns
CS*S	2	46781	23390.5	343.92	0.0000**
V*CS*S	8	867	108.4	1.59	0.1686ns
Error R*V*CS*S	30	2040	68.0		
Total	89	122303			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

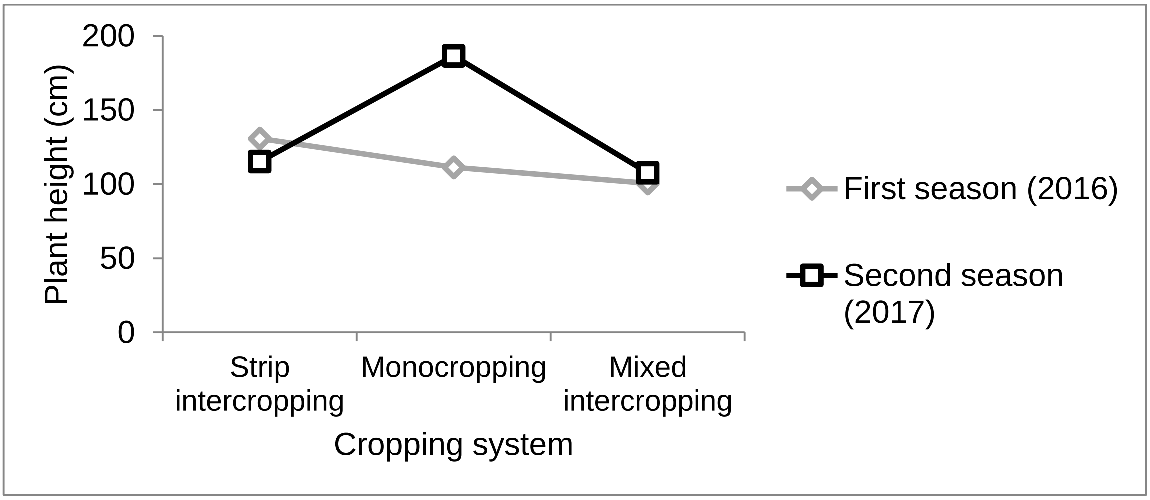

Figure 4.22: Interaction of cropping system x season for plant height in the 2016 and 2017 seasons

Table 4.30: Effect of variety, cropping system and season on phenological development of pigeonpea varieties during the 2015/16 and 2016/17 seasons

Variety (V)		
	Plant height (cm)	Number of primary branches
ICEAP 00661	123.89[a]	8.39[a]
ICEAP 87091	126.06[a]	8.39[a]
ICEAP 01101-2	126.28[a]	8.44[a]
ICEAP 00604	120.78[a]	8.11[a]
ICEAP 001284	119.44[a]	8.11[a]
Grand mean	122.89	8.29
SEM	3.6716	0.4503
	Cropping system (CS)	
Monocropping	158.20[a]	7.93[b]
Strip intercropping	106.47[b]	8.43[a]
Mixed intercropping	104.00[b]	8.50[a]
SEM	2.2431	0.2219
	Season (S)	
2015/16	134.22[a]	9.71[a]
2016/17	111.56[b]	6.87[b]
SEM	1.7386	0.2620

Means followed by the same letter in each column does not differ significantly at $P \geq 0.05$. SEM = Standard error of means

4.6.5 Number of pods per plant

The interaction between variety x cropping system x season (V x CS x S) showed no significant ($P \geq 0.05$) differences; however, there were significant ($P \leq 0.05$) differences observed on the interaction between cropping systems x seasons (CS x S) (Table 4.31). A greater number of pods per plant was recorded during both seasons, which was for strip intercropping (132.33 pods) for 2015/16 and 148.00 pods for the 2016/17 season. This was significantly higher than the 128.60 pods and 117.00 pods, which were recorded under monocropping during the 2015/16 and 2016/17 season, respectively (Figure 4.23).

These results are in close conformity with the findings of Zerihun *et al*. (2016) who observed a greater number of pods per plant under strip intercropping than monocropping. Mixed intercropping had the lowest number of pods (109.87) and (99.17) during 2016/17 and 2015/16, respectively (Figure 4.23). Reduction in the number of pods per plant under mixed intercropping was because of the high competition for growth resources such as water and nutrients.

The interactive effect between variety x season (V x S) showed significant differences. During the 2016/17 season, ICEAP 01101-2 and ICEAP 001284 produced the highest number of pods (176.89) and (158.78), respectively. This was significantly higher than the other three varieties (ICEAP 00604, 98.89 pods; ICEAP 87091, 95.11 pods; and ICEAP 00661, 95.13 pods) (Figure 4.24). Similarly, during the 2015/16 season, varieties ICEAP 01101-2 and ICEAP 001284 had the greatest number of pods (119.67 and 108.22, respectively), followed by ICEAP 00604 (109.00 pods) and ICEAP 87091 (105.78 pods). This implies that ICEAP 01101-2 and ICEAP 001284 were stable in grain production despite the variation in weather conditions in the two seasons. The lowest number of pods of 95.33 during 2015/16 was observed on ICEAP 00661 (Figure 4.24). The variation in number of pods per plant arose due to differences in genetic makeup of the varieties and response to other growth factors. These findings agree with findings of Cheboi *et al.* (2016) who recorded differences in number of pods per plant being due to genetic makeup. Similar findings were also observed by Silim and Omanga (2001) who reported significant differences between pigeonpea varieties due to their genetic characteristics. There were significant ($P \leq 0.05$) differences among pigeonpea varieties in terms of pods per plant (Table 4.31). Similar results were reported by Cheboi *et al.* (2016) and Hardev *et al.* (2016). Variety ICEAP 001284 had a greater number of pods per plant among the varieties with an average of 160.06 pods, followed by ICEAP 01101-2 (145.56 pods), ICEAP 00604 (103.94 pods) and ICEAP 87091 (100.44 pods) (Table 4.33). The variety with the lowest number of pods per plant was ICEAP 00661 (95.22 pods) (Table 4.33). The variation in the number of pods per plant arose due to differences in the genetic characteristics of varieties and response to other growth factors.

Similar results were reported by Cheboi *et al.* (2016) who recorded differences in the number of pods per plant being due to genetic makeup. The number of pods per plant was significantly ($P \leq 0.05$) affected by cropping systems (Table 4.31). The greatest number of pods per plant of 141.17 was observed under strip intercropping, while the lowest number of pods of 122.80 per plant was recorded under monocropping, followed by mixed intercropping with 99.17 pods (Table 4.33). The reduction in the number of pods per plant under mixed intercropping compared to strip intercropping might have resulted from inter- and intra-species competition for plant growth resources. Similar observations had been made in earlier studies by Dasbak and Asiegbu (2009) who opined that inter-specific competition for light, nutrients, water, air and other growth resources often resulted in depressed yield components and yields under mixed intercrop.

Table 4.31: Analysis of variance for number of pods per plant during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	3260.00	1630.20		
Variety (V)	4	63112.00	15778.00	6.91	0.0104**
Error Rep*V	8	18266.00	2283.20		
Cropping system (CS)	2	26599.00	13299.30	15.72	0.0001**
V*CS	8	10395.00	1299.30	1.54	0.2071ns
Error Rep*V*CS	20	16920.00	846.00		
Season (S)	1	1377.00	1376.70	1.99	0.1683ns
V*S	4	7843.00	1960.70	2.84	0.0415*
CS*S	2	4468.00	2234.00	3.23	0.0434*
V*CS*S	8	11724.00	1465.50	2.12	0.0649ns
Error R*V*CS*S	30	20718.00	690.60		
Total	89	184682.00			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

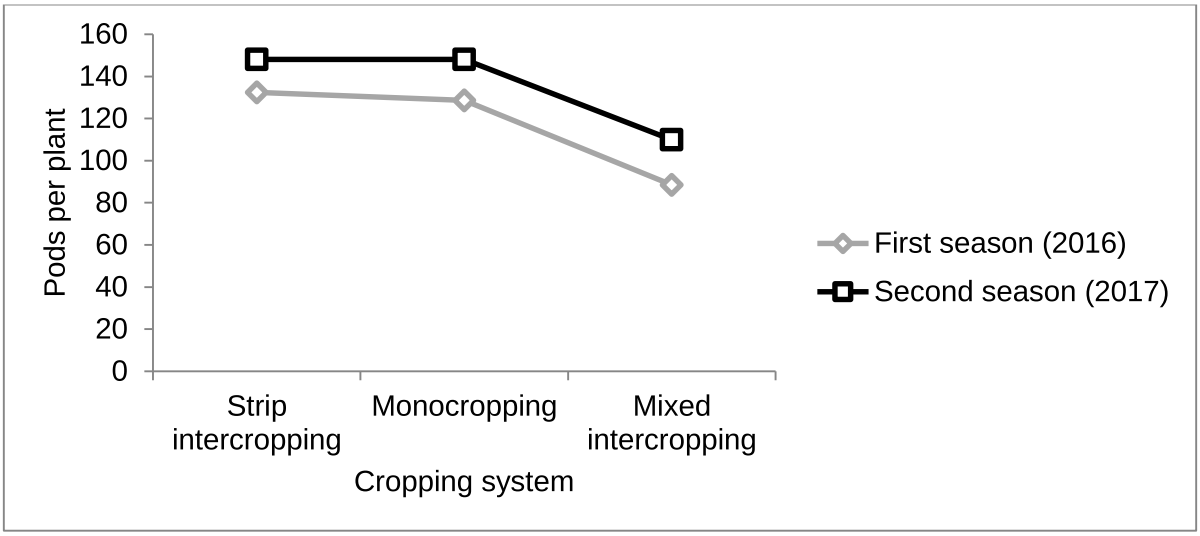

Figure 4.23: Interaction of cropping system x season for number of pods per plant during the 2016 and 2017 seasons

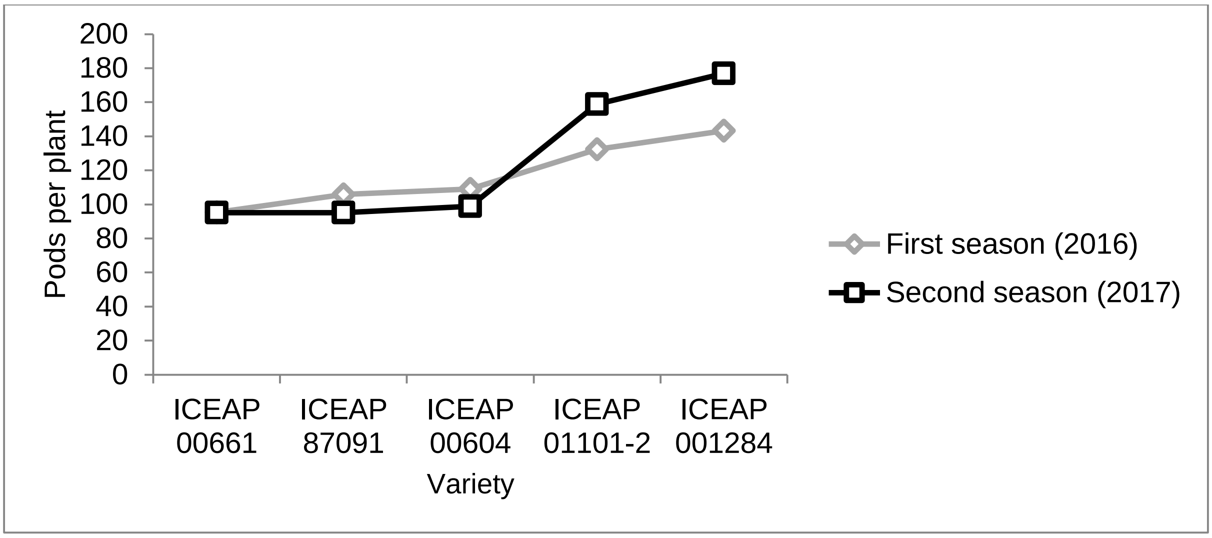

Figure 4.24: Interaction of cropping system x variety for the number of pods per plant during the 2016 and 2017 seasons

4.6.6 Pod length (cm)

The main effects of interaction between variety x cropping system x season (V x CS x S) were not significantly ($P \geq 0.05$) different regarding the pod length of pigeonpea (Table 4.32). In Table 4.32 below, the performance of pigeonpea varieties on pod length did not differ significantly ($P \geq 0.05$). Similar results of no significance were reported by Nam *et al.* (2001). Cropping systems showed no significant ($P \geq 0.05$) differences for pod length (Table 4.32). However, seasons showed significant ($P \leq 0.05$) differences on pod length; a longer pod mean length of 6.76 cm was recorded for 2016/17 as compared to 4.73 cm for the 2015/16 season (Table 4.33). Longer pods observed during the 2016/17 season were probably due to higher rainfall.

Table 4.32: Analysis of variance for pod length of pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	22.13	11.07		
Variety (V)	4	0.46	0.11	0.97	0.4735ns
Error Rep*V	8	0.95	0.12		
Cropping system (CS)	2	16.50	8.25	3.13	0.0657ns
V*CS	8	0.65	0.08	0.03	1.0000ns
Error Rep*V*CS	20	52.69	2.63		
Season (Y)	1	92.42	92.42	22.00	0.0001**
V*S	4	1.62	0.41	0.10	0.9827ns
CS*S	2	21.58	10.79	2.57	0.0934ns
V*CS*S	8	2.90	0.36	0.09	0.9994ns
Error R*V*CS*S	30	126.04	4.20		
Total	89	337.94			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

Table 4.33: Effect of variety, cropping system and season on yield parameters of pigeonpea varieties during the 2015/16 and 2016/17 seasons

Variety (V)	Number of pods per plant	Pod length(cm)
ICEAP 00661	95.22^{b}	5.76^{a}
ICEAP 87091	100.44^{b}	5.64^{a}
ICEAP 01101-2	145.56^{a}	5.70^{a}
ICEAP 00604	103.94^{b}	5.78^{a}
ICEAP 001284	160.06^{a}	5.84^{a}
Grand mean	121.04	5.74
SEM	15.928	0.1146
	Cropping system (CS)	
Monocropping	122.80^{b}	5.560^{ab}
Strip intercropping	141.17^{a}	5.333^{b}
Mixed intercropping	99.17^{c}	6.333^{a}
SEM	7.5101	0.4191
	Season (S)	
2015/16	117.13^{a}	4.73^{b}
2016/17	124.94^{a}	6.76^{a}
SEM	5.5402	0.4321

Means followed by the same letter in each column do not differ significantly at P ≥ 0.05. SEM = Standard error of means

4.6.7 Number of seed per pod

There were no significant (P ≥ 0.05) differences observed on the interaction between variety x cropping system x season (V x CS x S). However, the interaction between cropping system x season (CS x S) showed a significance difference (Table 4.34). The greatest number of seeds per pod of 5.67 was recorded for 2016/17 under mixed intercropping (due to small seed size). This was significantly greater than monocropping and strip intercropping, which had produced 5.27 seeds and 5.13 seeds, respectively (Figure 4.25). However, during the 2015/16 season, 4.47 and 4.00 seeds per pod were recorded for strip intercropping and mixed intercropping, respectively, while the lowest number of seeds was recorded for monocropping (Figure 4.25).

There were no significant (P ≥ 0.05) differences among pigeonpea varieties for number of seeds per pod (Table 4.34). Similarly, cropping systems showed no significant differences. However, seasons revealed significant differences with respect to number of seeds per pod (Table 4.34). The greatest number of seeds per pod of 5.36 was recorded for the 2016/17 season, which was significantly higher than the 4.00 recorded during the 2015/16 season (Table 4.37). The greater number of seeds per pod recorded during the 2016/17 season was probably due to longer pods observed during that season. The findings of these results are in close conformity with the findings of Ojwang *et al.* (2016) who reported that the number of seeds per pod was positively correlated to pod length, and a greater number of seeds were observed due to longer pods.

Table 4.34: Analysis of variance for number of seeds per pod in five pigeonpea

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	3.20	1.60		
Variety (V)	4	1.22	0.31	2.68	0.1095ns
Error Rep*V	8	0.91	0.11		
Cropping system (CS)	2	4.07	2.03	4.95	0.0680ns
V*CS	8	2.38	0.30	0.72	0.6698ns
Error Rep*V*CS	20	8.22	0.41		
Season (S)	1	42.71	42.71	98.56	0.0000**
V*S	4	0.07	0.02	0.04	0.9970ns
CS*S	2	5.76	2.88	6.64	0.0041**
V*CS*S	8	0.47	0.06	0.13	0.9970ns
Error R*V*CS*S	30	13.00	0.43		
Total	89	82.00			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

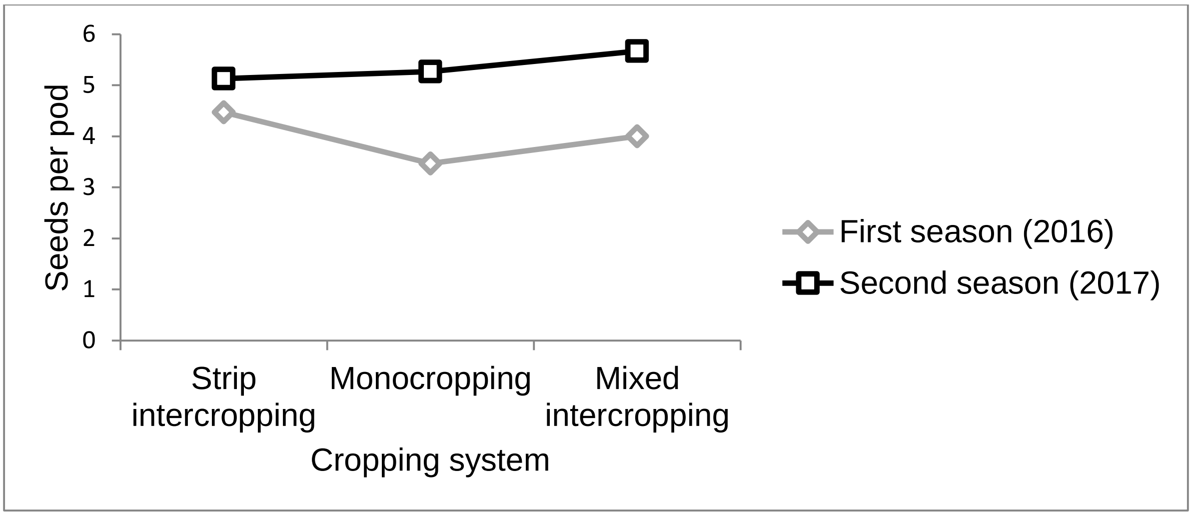

Figure 4.25: Interaction for cropping system x season for number seeds per pod during the 2016 and 2017 seasons

4.5.8 Hundred seed weight (g)

The interaction between cropping system x season (CS x S) showed significant differences (Table 4.35). During the 2016/17 season, all cropping systems exhibited higher hundred-seed weight, which was recorded under strip intercropping (13.90 g), monocropping (13.77 g) and mixed intercropping (13.26 g). They were significantly higher than monocropping (7.01 g), strip intercropping (5.09 g) and mixed intercropping (3.63 g) recorded during the 2015/16 season (Figure 4.26). The small size seed exhibited by mixed intercropping supported the reason for the higher number of seeds per pods reported in 4.6.7.

There were no significant ($P < 0.05$) differences among pigeonpea varieties for 100 seeds mass (Table 4.35). Similar results of no significant differences were reported by Nam *et al.* (2001). Cropping systems and seasons showed significant ($P \leq 0.05$) differences among pigeonpea varieties (Table 4.35). The greatest mass of 10.39 g and 9.49 g was recorded for monocropping and strip intercropping, respectively, and the lowest for mixed intercropping (7.64 g) (Table 4.37). The low seed mass recorded for mixed intercropping could have arisen due to the effect of competition for growth resources arising from poor spacing. Seasons showed highly significant ($P \leq 0.05$) differences on 100 seed weight, where the greatest mass of 13.64 g was observed during 2016/17 rather than the 5.24 g during the 2015/16 season (Table 4.37).

Table 4.35: Analysis of variance for hundred seed weight of five pigeonpea during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	38.75	19.37		
Variety (V)	4	5.24	1.31	0.36	0.8310ns
Error Rep*V	8	29.18	3.65		
Cropping system (CS)	2	56.78	28.39	8.33	0.0023**
V*CS	8	19.23	2.40	0.71	0.6833ns
Error Rep*V*CS	20	68.12	3.41		
Season S)	1	1586.51	1586.51	614.83	0.0000**
V*S	4	10.99	2.75	1.06	0.3910ns
CS*S	2	32.87	16.43	6.37	0.0049**
V*CS*S	8	20.24	2.53	0.96	0.4699ns
Error R*V*CS*S	30	77.41	2.58		
Total	89	1945.33			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

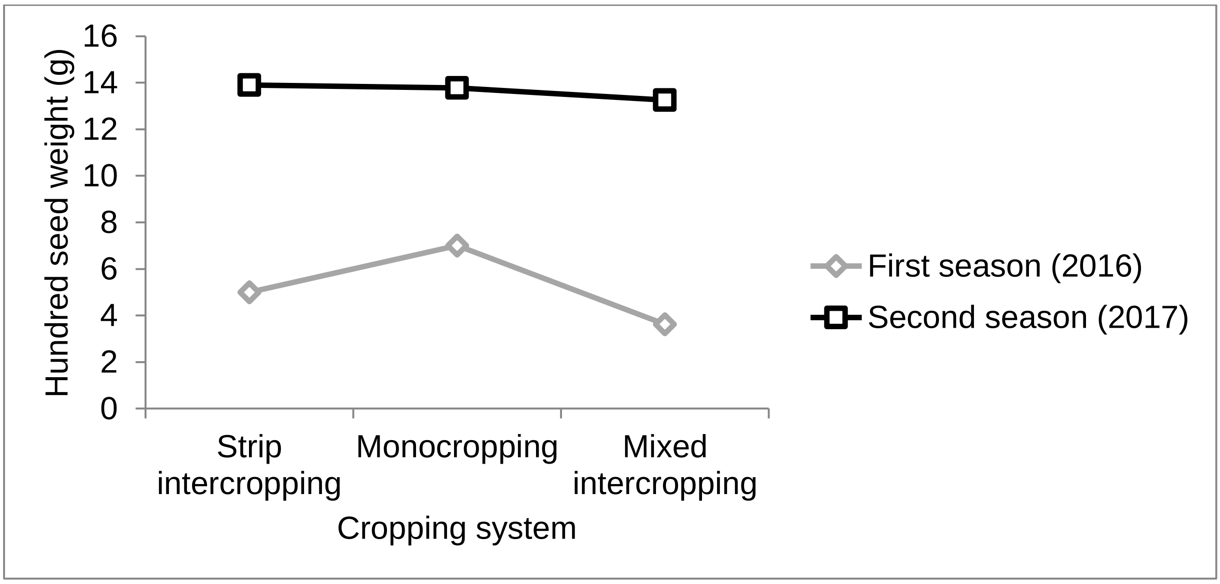

Figure 4.26: Interaction of cropping system x season for hundred seed weight during the 2016 and 2017 seasons

4.6.9 Grain yields (kg/ha)

The interaction between variety x cropping system (V x CS) showed significant differences on grain yields of pigeonpea (Table 4.36). The top yielder pigeonpea varieties under strip intercropping were ICEAP 001284 (875 kg ha^{-1}), ICEAP 00604

(805 kg ha^{-1}) and ICEAP 01101-2 (747 kg ha^{-1}). Similarly, under monocropping, the three varieties outperformed other varieties with mean grain yields of 680 kg ha^{-1} (ICEAP 001284), 619 kg ha^{-1} (ICEAP 01101-2) and 587 kg ha^{-1} (ICEAP 00604) (Figure 4.27). Other varieties (ICEAP 87091 and ICEAP 00661) under monocropping and strip intercropping yielded below 400 kg ha^{-1} (Figure 4.27). Differences in yields among pigeonpea varieties were probably due to the genetic makeup of the varieties. This agrees with findings of Sujatha and Babalad (2018) who reported significant differences due to genetic characteristics. Similar significant variations in yields among pigeonpea varieties were reported by Manivel *et al.* (2012). The superior performance of varieties under strip intercropping suggests low competition for growth factors.

The interaction between variety x season (V x S) showed significant differences, where most of the varieties yielded more during 2016/17 than during the 2015/16 season (Figure 4.28). The increase in yields was attributed to more pods per plant recorded during the 2016/17 season, which had been enhanced by better rainfall distribution. This agrees with findings of Egbe and Vange (2008) who observed a positive correlation on pigeonpea genotype between the number of primary branches, number of pods per plant and where high grain yields were recorded because of high yield components. The top yielders during the 2016/17 season were ICEAP 001284 and ICEAP 01101-2 with 671 kg ha^{-1} and 627 kg ha^{-1}, respectively (Figure 4.28). Furthermore, varieties that obtained high yields during the 2015/16 season were ICEAP 001284 (504 kg ha^{-1}) and ICEAP 00604 (541 kg ha^{-1}) (Figure 4.28). This suggests that the yield of different pigeonpea varieties may depend on seasons and other environmental factors (temperatures and rainfall). Similar observations were made by Zerihun (2016) who reported significant differences in grain yield due to environmental variability, the genetic factor and crop management.

There were highly significant differences observed among pigeonpea varieties (Table 4.36). The top yielder varieties were ICEAP 001284 (587 kg ha^{-1}), ICEAP 00604 (520 kg ha^{-1}) and ICEAP 01101-2 (484 kg ha^{-1}), whereas a low grain yield was observed for ICEAP 87091 (404 kg ha^{-1}) and ICEAP 00661 (391 kg ha^{-1}) (Table 4.37). Differences in grain yields observed may be contributed to the genetic makeup of the different cultivars. Similar results were observed by Cheboi *et al.* (2016) who recorded significant differences among pigeonpea due to their genetic characteristics. The high yields of three varieties might be because they are determinate cultivars and partitioned their photosyntates more on grains. Grain yields were significantly affected by cropping systems and seasons, where the highest grain yields of 656 kg ha^{-1} were recorded under strip intercropping as compared to 207 kg ha^{-1}, which was recorded under mixed intercropping (Table 4.37). The reduction in grain yield under mixed intercropping compared to strip intercropping might have resulted from intra-species competition for plant growth resources. Similar observations had been made in earlier studies (Egbe and Adeyemo, 2006; Dasbak and Asiegbu, 2009). These authors opined that inter-specific competition for light, nutrients, water, air and other growth resources often resulted in depressed yields of mixed intercrop plots.

Seasons resulted in significant differences, when higher grain yields of 569 kg ha^{-1} were recorded during 2016/17 than in the 2015/16 season, which produced 386 kg ha^{-1} (Table 4.37). The reduced yields that were observed during the 2015/16 season were due to low rainfall during the vegetative stage, which caused a reduction in yields and yield components (pods per plant, seeds per pod). These results are in close conformity with previous findings of Sarika *et al.* (2013) who reported that low rainfall during the anthesis stage causes a drastic reduction of pods per plant, seeds per pod and yields.

Table 4.36: Analysis of variance for grain yields on pigeonpea varieties during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	185682	92841		
Variety (V)	4	481385	120346	3.96	0.0464*
Error Rep*V	8	243185	30398		
Cropping System (CS)	2	3399654	1699827	144.58	0.0000**
V*CS	8	553574	69197	5.89	0.0006**
Error Rep*V*CS	20	235132	11757		
Season (S)	1	755213	755213	17.28	0.0002**
V*S	4	335003	83751	1.92	0.0335*
CS*S	2	562121	281061	6.43	0.6247ns
V*CS*S	8	290466	36308	0.83	0.5828ns
Error R*V*CS*S	30	1311261	43709		
Total	89	8352676			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

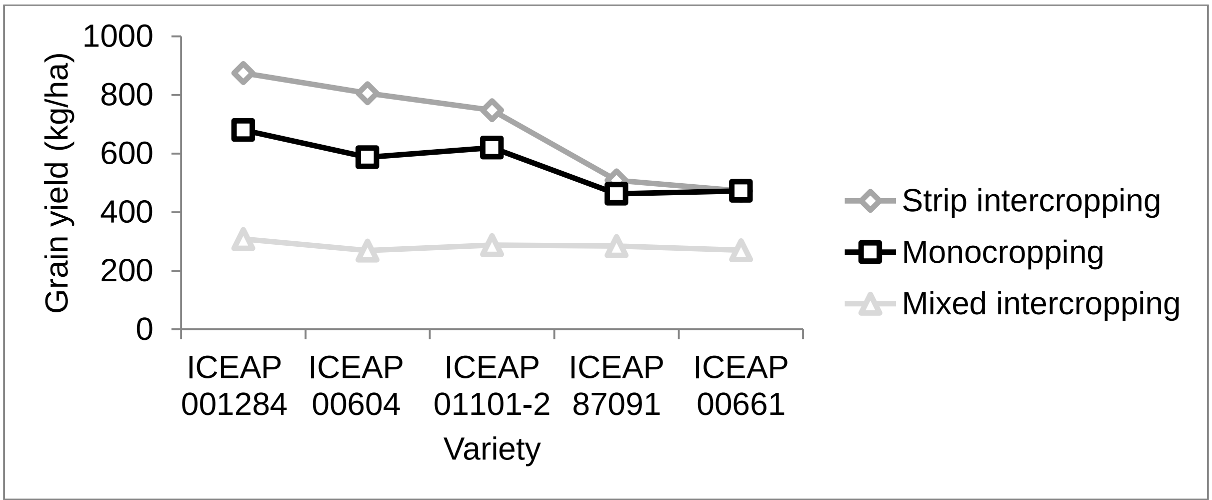

Figure 4.27: Interaction of variety x cropping system for grain yield (kg/ha) during the 2016 and 2017 seasons

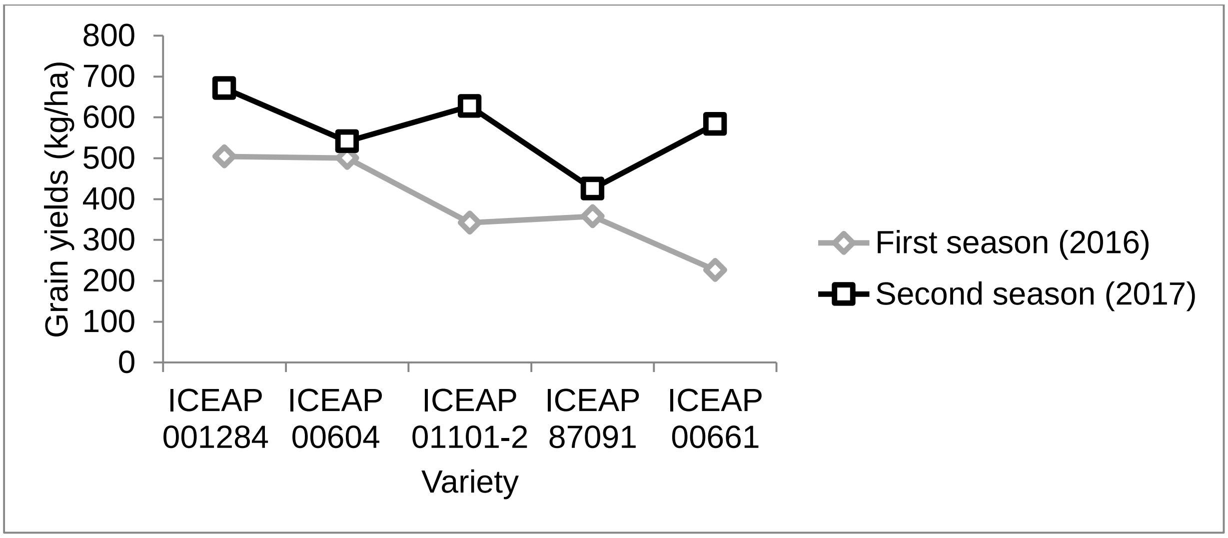

Figure 4.28: Interaction of variety x season for grain yield (kg/ha) in the 2016 and 2017 seasons

Table 4.37: Effect of variety, cropping system and season on yield parameters of pigeonpea varieties during the 2015/16 and 2016/17 seasons

Variety (V)	Number of seed per pod	Hundred seed weight (g)	Grain yields (kg/ha)
ICEAP 00661	4.61[b]	9.82[a]	391.50[b]
ICEAP 87091	4.67[ab]	9.18[a]	404.80[b]
ICEAP 01101-2	4.61[b]	9.34[a]	484.81[ab]
ICEAP 00604	4.56[b]	9.25[a]	520.63[ab]
ICEAP 001284	4.89[a]	9.63[a]	587.72[a]
Grand mean	4.67	9.44	477.89
SEM	0.1125	0.6367	58.117
	Cropping system (CS)		
Monocropping	4.87[a]	10.39[a]	570.00[b]
Strip intercropping	4.80[a]	9.49[a]	656.11[a]
Mixed intercropping	4.83[a]	7.64[b]	207.57[c]
SEM	0.1656	0.2245	27.996
	Season (S)		
2015/16	4.00[b]	5.24[b]	386.29[b]
2016/17	5.36[a]	13.64[a]	569.50[a]
SEM	0.1388	0.3387	44.075

Means followed by the same letter in each column do not differ significantly at P ≥ 0.05. SEM = Standard error of means

4.7 Performance of Maize at Ga-Thaba

4.7.1 Number of days to 50% tasselling

The interactive effect between cropping system x season (CS x S) revealed significant differences (Table 4.38). Maize planted during the 2015/16 seasons under all cropping systems tasselled earlier than in 2016/17, which had mean days that ranged between 72-73 and 75-78 days during 2015/16 and 2016/17, respectively (Figure 4.29). Seasonal variations of phenological development of maize were largely attributed to differences in environmental factors such as rainfall and temperatures. This is supported by the work done by Tandzi *et al*. (2015) who observed significant differences on phenological development of maize across different environments.

The results revealed that there were no significant ($P \geq 0.05$) differences with respect to the number of days of 50% silking under different cropping systems (Table 4.33). Seasons revealed significant ($P \leq 0.05$) differences for 50% tasselling (Table 34). Maize planted during the 2015/16 season tasselled earlier at 73.09 days than during the 2016/17 season, which attained tasselling at 76.20 days (Table 4.40). Late tasselling during the 2016/17 season was probably due to lower rainfall during the reproductive stage, which led to delayed tasselling. This was supported by the work done by Otegui and Slafer (2004) who reported that water stress during the reproductive phase delays tasselling and silk emergence relative to pollen shed.

Table 4.38: Analysis of variance for number of days to 50% tasselling of maize

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	90.422	45.21		
Cropping system (CS)	2	14.289	7.14	0.59	0.5945ns
Error Rep*CS	4	48.11	12.03		
Season (S)	1	217.78	217.78	73.26	0.0000**
CS*S	2	42.16	21.08	7.09	0.0015**
Error	78	231.87	2.973		
Total	89	644.62			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

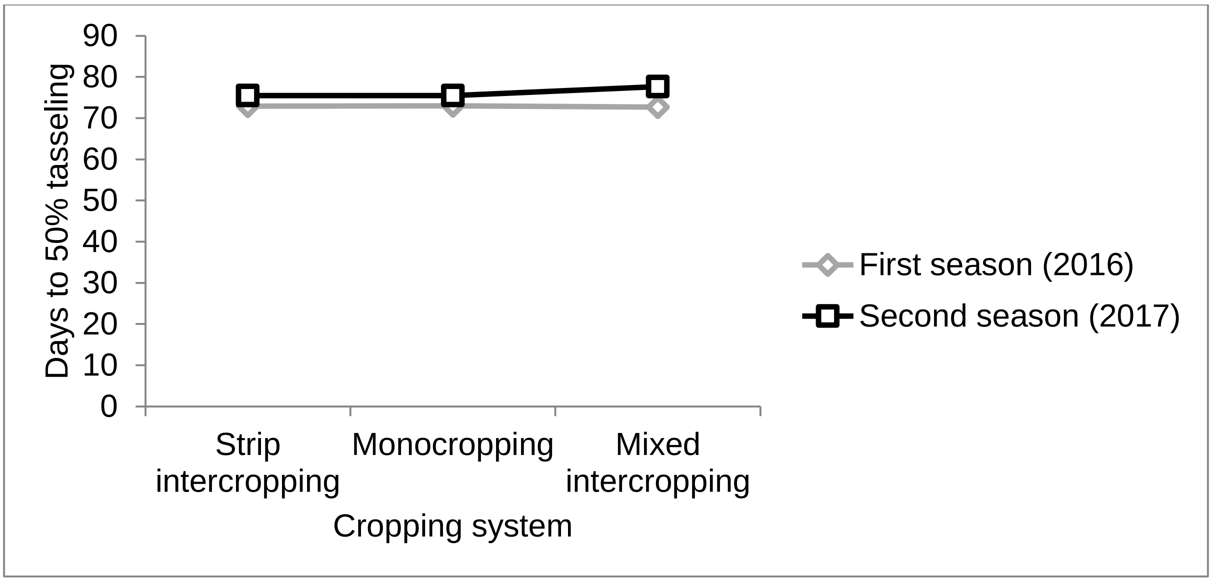

Figure 4.29: Interaction of cropping system x season for number of days to 50% tasselling during the 2016 and 2017 seasons

4.7.2 Number of days 50% silking

The interaction between cropping system x season (CS x S) showed significant differences for the number of days to 50% silking (Table 4.39). During the 2015/16 season under all cropping systems, there were no significant differences. However, significant differences were observed during the 2016/17 season. Mixed intercropping showed the maximum number of days (89.33) to reach 50% silking. This was significantly higher than strip intercropping and monocropping, which needed 84.53 and 84.40 days, respectively (Figure 4.30). Significant differences were observed regarding the number of days to 50% silking as influenced by different seasons (Table 4.39). Similar results of significant differences regarding the number of days to 50% silking across seasons was reported by Tandzi *et al*. (2015). Maize took the maximum number of days (86.09) to attain 50% silking during the 2016/17 season as compared to 77.42 days recorded for 2015/16 (Table 4.40).

Table 4.39: Analysis of variance for number of days to 50% silking of maize during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	279.82	139.91		
Cropping system (CS)	2	90.96	45.48	1.48	0.3306ns
Error Rep*CS	4	123.04	30.76		
Season (S)	1	1690.00	1690.00	602.65	0.0000**
CS*S	2	154.07	77.03	27.47	0.0000**
Error	78	218,73	2.80		
Total	89	25556.62			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

Table 4.40: Effect of cropping system and season on phenological development of maize during the 2015/16 and 2016/17 seasons

Cropping system (CS)	Number of days to 50% tasselling	Number of days to 50% silking
Monocropping	74.57[a]	81.20[a]
Strip intercropping	74.00[a]	80.90[a]
Mixed Intercropping	75.12[a]	83.17[a]
SEM	0.8955	0.3232
Season (S)		
2015/16	73.10[b]	86.09[a]
2016/17	76.20[a]	77.42[b]
SEM	0.3635	0.3530

Means followed by the same letters in each column do not differ significantly at $P \geq 0.05$. SEM = Standard error of means

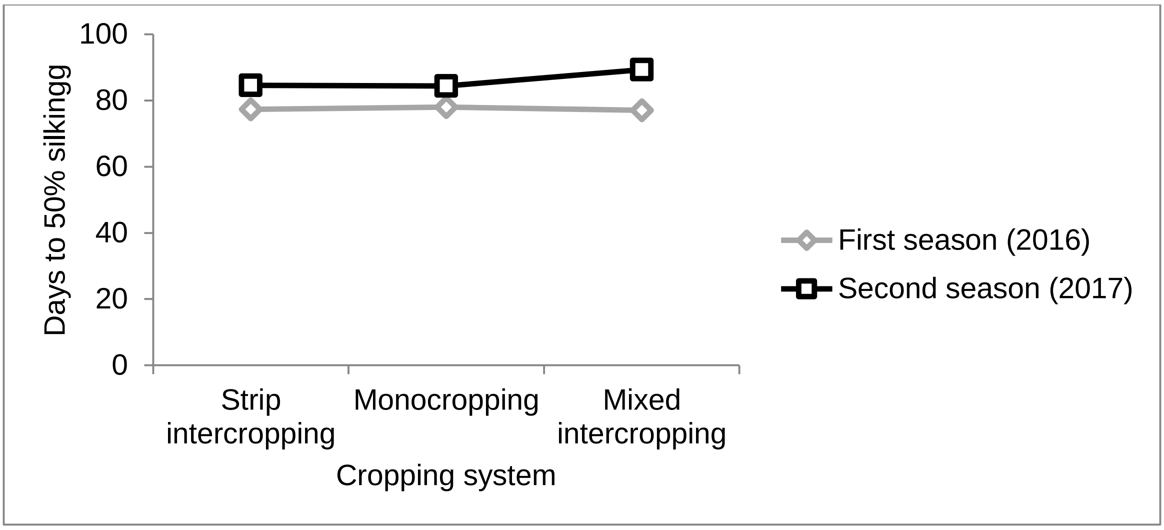

Figure 4.30: Interaction of cropping system x season for number of days to 50% silking during the 2016 and 2017 seasons

4.7.3 Plant height (cm)

The interaction between cropping system x season (CS x S) showed significant differences for plant height (Table 4.41). Strip intercropping during the 2015/16 season produced taller plants of 141.32 cm. This was significantly higher than mixed intercropping (89.88 cm) and monocropping (88.09 cm) (Figure 4.31). During the 2016/17 season, monocropping and strip intercropping produced taller plants with a mean height of 135.47 cm and 130.47 cm, respectively, as compared to mixed intercropping, which had a mean height of 87.33 cm (Figure 4.31).

Plant height was significantly ($P \leq 0.05$) affected by the different cropping systems and seasons (Table 4.41). Maize plant height of 135.89 cm in strip intercropping was significantly higher than mean plant heights of 111.74 cm and 88.60 cm, which were observed under monocropping and mixed intercropping, respectively (Table 4.43). This observation is similar to the findings of Geren *et al.* (2008) who recorded higher maize plant heights under intercropping as compared to monocropping. Seasons had an influence on maize plant height, where the 2016/17 season produced a taller plant of 117.76 cm as compared to 106.40 cm for the 2015/16 season (Table 4.43).

Table 4.41: Analysis of variance for maize plant height during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	593.1	296.6		
Cropping system (CS)	2	33549.0	16774.5	34.86	0.0029*
Error Rep*CS	4	1924.7	481.2		
Season (S)	1	12924.3	2901.01	10.94	0.0014*
CS*S	2	20692.4	7462.2	28.13	0.0000*
Error	78	74584.5	265.3		
Total	89				

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and * Significant at (P ≤ 0.05)

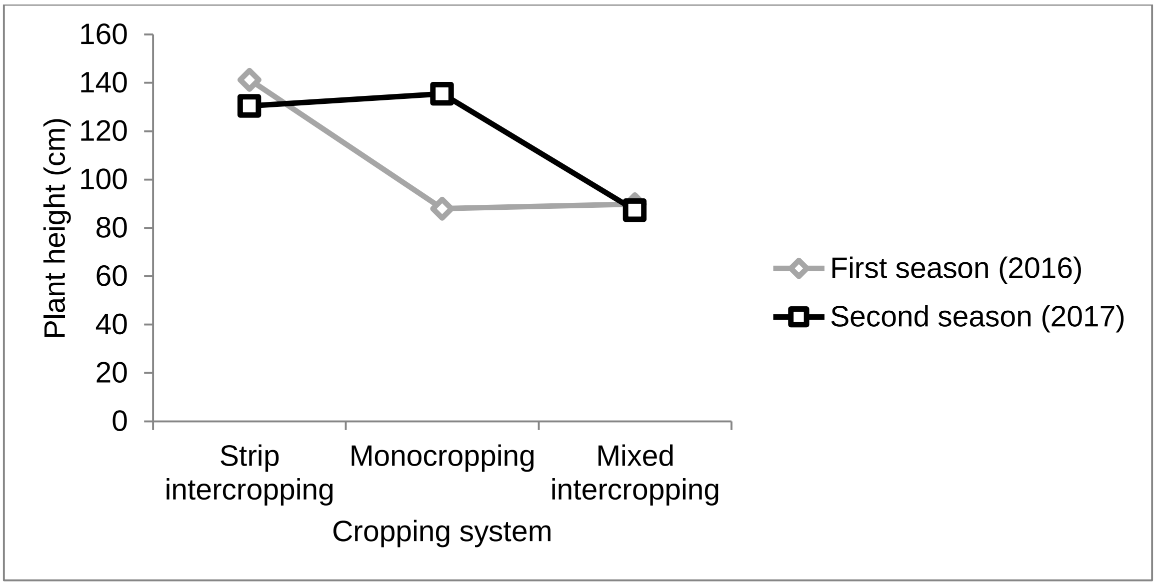

Figure 4.31: Interaction of cropping system x season for plant height during the 2016 and 2017 seasons

4.7.4 Number of cobs per plant

No significant (P ≤ 0.05) differences were observed regarding the number of cobs per plant as influenced by different cropping systems and seasons (Table 4.42). Similarly, the interaction of cropping systems x seasons (CS x S) also showed no significant (P≤ 0.05) differences (Table 4.42). This implies that the number of cobs per plant is genetically determined and not influenced by the environment.

Table 4.42: Analysis of variance for number of cob per plant during 2016 and 2017 seasons.

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	2.82	1.41		
Cropping system (CS)	2	1.09	0.54	0.49	0.6400ns
Error Rep*cps	4	4.44	1.11		
Season (S)	1	1.88	1.87	6.12	0.1002ns
CS*S	2	1.49	0.74	2.43	0.1000ns
Error	78	23.93	0.30		
Total	89	35.66			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and ns = Not significant

Table 4.43: Effect of cropping system and season on phenological development of maize during the 2015/16 and 2016/17 seasons

Cropping system (CS)	Plant height (cm)	Number of cob per plant
Monocropping	111.74[a]	1.80[a]
Strip intercropping	135.89[b]	1.53[a]
Mixed Intercropping	88.60[c]	1.80[a]
SEM	5.6638	0.2722
	Season (S)	
2015/16	106.76[a]	1.53[a]
2016/17	117.76[a]	1.52[a]
SEM	3.4337	0.1168

Means followed by the same letter in each column does not differ significantly at P ≥ 0.05. SEM = Standard error of means

4.7.5 Cob length (cm)

The interactive effect of cropping systems x season (CS x S) showed significant (P ≤ 0.05) differences for cob length (Table 4.44). During the 2015/16 season, strip intercropping produced the longest cobs of 20.00 cm. This was significantly longer than the 14.33 cm and 12.27 cm, which were recorded under monocropping and mixed intercropping, respectively. Monocropping produced longer cobs of 14.07 cm during the 2016/17 season as compared to the 13.67 cm and 13.87 cm under strip intercropping and mixed intercropping, respectively (Figure 4.32). The findings of this study agree with the studies by Takim (2012) that reported longer cobs under monocropping as compared to intercropping. There were significant (P ≤ 0.05) differences on maize cob length under different cropping systems and seasons (Table 4.38). Strip intercropping significantly produced longer cobs of 16.93 cm, followed by 14.20 cm and 12.96 cm for monocropping and mixed intercropping, respectively (Table 4.47). Seasons influenced maize cob length, with 2015/16 producing longer cobs of 15.53 cm as compared to the 13.87 cm achieved during the 2016/17 season (Table 4.47).

Table 4.44: Analysis of variance for maize cob length during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	62.51	32.26		
Cropping system (CS)	2	247.79	123.89	8.71	0.0030**
Error Rep*cps	4	56.88	14.22		
Season (S)	1	62.25	62.25	20.21	0.0000**
CS*S	2	235.33	117.66	38.20	0.0000**
Error	78	240.24	3.08		
Total	89	904.10			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability and * Significant at (P ≤ 0.05)

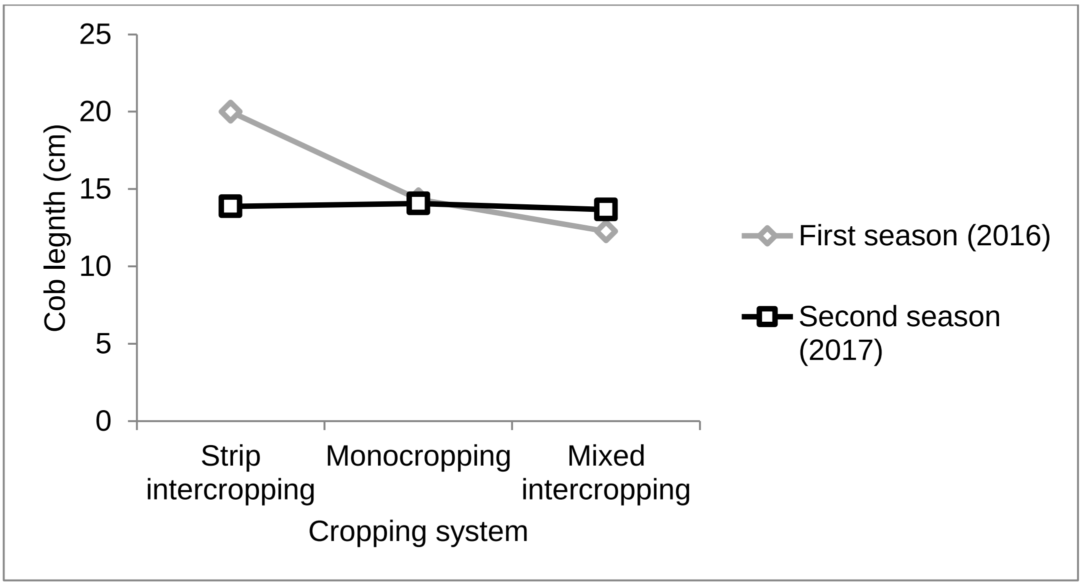

Figure 4.32: Interaction of cropping system x season for maize cob length during the 2016 and 2017 seasons

4.7.6 Grain yields (kg/ha)

The interaction between cropping system x season (CS x S) showed no significant differences on grain yield (Table 4.45). Similarly, seasons showed no significant differences (Table 4.39). However, grain yield was affected by cropping systems (Table 4.45). The findings of this study agree with the studies by Ndiso *et al.* (2017) who reported that grain weight of maize was significantly affected by the cropping system. A high grain yield of 4546 kg ha^{-1} was recorded under strip intercropping, followed by monocropping (2494 kg ha^{-1}) and mixed intercropping (1348 kg ha^{-1}) (Table 4.47). This was supported by the work done by Yilmaz *et al*. (2007) who reported the highest yield for intercropping rather than for maize monocropping. High yields under strip intercropping plots has been attributed to less competition for resources as compared to maize yields under mixed intercropping.

Table 4.45: Analysis of variance for maize grain yield kg/ha during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	1498466	749233		
Cropping system (CS)	2	2.82E+08	1.41E+08	148.03	0.0002**
Error Rep*CS	4	3808987	952247		
Season (S)	1	202572	202572	0.06	0.8048ns
CS*S	2	724071	362036	0.11	0.8961ns
Error	78	2.57E+08	3294770		
Total	89				

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at (P ≤ 0.05)

4.7.7 Stover yield (kg/ha)

The interaction between cropping system x season (CS x S) showed no significant differences for maize stover (Table 4.46). Similarly, seasons showed no significant differences. However, maize stover was affected by cropping systems (Table 4.46). High stover of 2107 kg ha^{-1} was recorded under strip intercropping, followed by monocropping (1380 kg ha^{-1}) and mixed intercropping (856 kg ha^{-1}) (Table 4.47). This result contradicts previous findings of Teshome *et al. (*2015) who reported higher biomass of maize (19.00 t ha^{-1}) under sole-cropped maize rather than that under intercropped maize with soybean (18.67 t ha^{-1}). High stover under strip intercrop plots has been attributed to less competition for resources as compared to maize stover under mixed intercropping.

Table 4.46: Analysis of variance for maize stover kg/ha during the 2016 and 2017 seasons

Source of variation	DF	SS	MS	F	P
Replication (Rep)	2	71877	35938		
Cropping system (CS)	2	2876268	1438134	29.00	0.0042**
Error REP*CS	4	198369	49592		
Season (S)	1	302699	302699	4.66	0.1340ns
CS*S	2	694652	347326	5.34	0.1095ns
Error	78	5069417	64993		
Total	89	9213282			

DF = degree of freedom, SS = sum of squares, MS = mean squares, P = Probability, ns = Not significant and * Significant at ($P \leq 0.05$)

Table 4.47: Some of maize yield parameters as influenced by different cropping systems and seasons

Cropping system (CS)	Cob length (cm)	Grain yield (kg/ha)	Stover (kg/ha)
Monocropping	14.20^{b}	2494^{b}	1380^{b}
Strip Intercropping	16.93^{a}	4546^{a}	2107^{a}
Mixed intercropping	12.96^{b}	1348^{c}	856^{c}
SEM	0.9736	252.39	217.59
Season (S)			
2015/16	15.53^{a}	3177^{a}	2053^{a}
2016/17	13.87^{b}	3082^{a}	2009^{a}
SEM	0.3700	383.10	269.93

Means followed by the same letter in each column do not differ significantly at $P \geq 0.05$. SEM = Standard error of means

4.8 Assessment of Intercropping Productivity

4.8.1 Land Equivalent Ratio (LER)

The calculated LER for two crops over two seasons under strip intercropping ranged from 1.58 and 1.96, whereas under mixed intercropping, it ranged between 0.22 and 0.78 in both seasons. The mean for LER was greater than 1; therefore indicated more efficient and productive land utilisation by strip intercropping compared with mixed intercropping. This was supported by the Dahmardeh (2013) who explained that the greater LER could be attributed to the morphological differences of the two crops and the optimal utilisation of resources. According to Quiroz and Marin (2003), there was higher LER in maize-based intercropping systems compared to respective sole cropping. Similar LER values greater than 1.0 in maize/pigeonpea intercropping have also been reported (Egbe and Adeyemo, 2006; Smith *et. al.,* 2001).

Table 4.48. Partial and total LER for the component crops under strip intercropping and mix intercropping

2015/16 season						
	Strip intercropping			Mixed intercropping		
Crop mixture	$PLER_{maize}$	$PLER_{pigeonpea}$	LER_T	$PLER_{maize}$	$PLER_{pigeonpea}$	LER_T
ICEAP 001284 +Maize	1.12	1.05	2.17	0.22	0.26	0.48
ICEAP 00604 +Maize	0.90	1.09	1.99	0.10	0.13	0.23
ICEAP 00661 +Maize	0.92	0.72	1.64	0.88	0.70	1.58
ICEAP 01101-2 +Maize	0.66	0.79	1.45	0.30	0.35	1.65
ICEAP 87091 +Maize	1.71	1.13	1.84	0.83	1.09	1.92
Mean	0.86[a]	0.96[a]	1.82[a]	0.47[a]	0.51[a]	0.98[a]
P-level	0.0465	0.7094	0.0344	0.5491	0.7193	0.6755
2016/17 season						
	Strip intercropping			Mixed intercropping		
Crop mixture	$PLER_{maize}$	$PLER_{pigeonpea}$	LER_{total}	$PLER_{maize}$	$PLER_{pigeonpea}$	LER_{total}
ICEAP 001284 +Maize	0.73	1.02	1.75	0.23	0.20	0.43
ICEAP 00604 +Maize	0.88	0.97	1.85	0.28	0.39	0.67
ICEAP 00661 +Maize	0.86	0.78	1.64	0.13	0.09	0.22
ICEAP 01101-2 +Maize	0.89	1.16	2.05	0.36	0.40	0.76
ICEAP 87091 +Maize	0.79	0.72	1.51	0.14	0.18	0.32
Mean	0.83[a]	0.93[a]	1.76[a]	0.23[a]	0.25[a]	0.48[a]
	0.5674	0.8750	0.0462	0.0564	0.7801	0.6755

PLER = partial Land Equivalent Ratio and LER_T = total Land Equivalent Ratio

CHAPTER 5:

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Significant differences existed in most variables measured as this include number of days to 50% flowering and 90% maturity, plant height, number of primary branches as well as yield and yield components among the evaluated pigeonpea varieties. Parameters such as days to 50% flowering and 90% maturity, plant height, pods per plant and grain yield were influenced with determinacy, temperature and rainfall distribution. Two pigeonpea varieties, ICEAP 001284 and ICEAP 00604, were regarded as early in terms of flowering and maturity as compared to ICEAP 01101-2, ICEAP 87091 and ICEAP 00661 at the UL Farm. Early varieties took <110 days to maturity, whereas others took 111-120 days. There were highly significant differences regarding the number of days to 50% flowering in both seasons. This variation was due to the fact that the varieties were exposed to different climatic conditions (temperatures and rainfall) and determinacy. During both seasons, most of the varieties at the UL Farm flowered early, with a mean of less than 113 days. Grain yields proved to be influenced by yield parameters such as pods per plant, pod length and number of seeds per pod. The top yielders at the UL Farm were ICEAP 001284 and ICEAP 01101-2, with mean grain yields >700 kg/ha during both seasons.

At Ga-Thaba, two pigeonpea varieties (ICEAP 001284 and ICEAP 00604) were regarded as early in terms of flowering and maturity as compared to ICEAP 01101-2, ICEAP 87091 and ICEAP 00661. Early varieties took <118 days to maturity, whereas others took 122-126 days. Variation in number of days to flowering and maturity of the varieties was due to their genetic makeup. The top yielders during both seasons at Ga-Thaba were ICEAP 001284 and ICEAP 00604, with mean grain yields of 587 kg ha^{-1} and 520 kg ha^{-1}, respectively. Grain yields during both seasons were influenced by environmental variability and genetic factors.

Differences in grain yield obtained across locations and seasons suggest that pigeonpea yield is influenced by seasons, which in turn are affected by environmental factors (temperatures and rainfall). In both seasons, cropping systems had a significant effect on maize and pigeonpea yields, where high yields were recorded under strip intercropping in both locations, but reduced under mixed intercropping. The calculated total LER for the two crops in both locations was reported as positive as and higher than 1, which suggests a favourable grain yield advantage for maize-pigeonpea under strip intercropping over mixed intercropping. Locations showed an effect on most of pigeonpea variables, where most of the varieties at the UL Farm flowered earlier with a mean of <113 days, while at Ga-Thaba, the result was >114 days. A higher yield of >700 kg ha^{-1} during both seasons was observed at the UL Farm compared to the <600 kg ha^{-1} at Ga-Thaba. This indicates that pigeonpea performs better in areas that receive better rainfall than in drier areas.

5.2 Conclusion and Recommendations

Among the five varieties evaluated, ICEAP 001284, ICEAP 00604 and ICEAP 01101-2 performed well and were selected for cultivation under strip intercropping because of their early maturity and high yields. Cropping systems were mostly responsible for significant differences in terms of pigeonpea and maize yields. Strip intercropping generally improved the yield of maize and pigeonpea, whereas under mixed intercropping, yields were significantly lower. Pigeonpea cultivars with a shorter number of days to flowering and maturity such as ICEAP 001284 and ICEAP 00604 are considered to be most suitable under rainfed conditions because of their ability to escape drought conditions by maturing early. The calculated LER for the cropping mixture was greater than 1, which suggests that the two-fold grain yields return for pigeonpea-maize strip intercropping makes is possible for using the same land area compared to monocropping.

The agronomic characterisation of pigeonpea in the Limpopo Province provided reliable knowledge and more information on pigeonpea adaptation for both the UL Farm and Ga-Thaba. Varieties ICEAP 001284, ICEAP 00604 and ICEAP 01101-2 should be recommended for cultivation because of their early maturity and higher yield potential. These farmers should also be introduced to strip intercropping through on-farm demonstrations. Future research should include farmer evaluation of the various crops, planting methods as well as their response to research conducted on their farms and the alternative planting/crop method demonstrations.

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