Influence of planting techniques and maturity group on soya bean (*Glycine max* L.) yield in different agro-ecologies

by

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The influence of maturity group, plant density and row width on the growth, yield components and yield of soya beans (*Glycine max* L.) in the North Eastern Free State between Vrede and Cornelia

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Abstract

In South Africa soya beans are mainly produced in the Mpumalanga and Free State provinces, while within the Free State, production is concentrated in the North Eastern Free State. It is widely known that soya bean yield is influenced by agronomic inputs such as, maturity group, plant density, row width as well as planting date. Extensive research was done globally on these agronomic inputs. However, very little, if any research was done in South Africa, especially in the North Eastern Free State.

In an attempt to evaluate the yield response to different maturity groups, plant densities, row widths and planting dates, three trials were conducted on farmer's fields over two seasons (2016/17 and 2017/18) in the North Eastern Free State at three agro-ecologically different experimental sites. The same maturity groups (MG 4.5, MG 5 and MG 6) was planted at different plant densities, row widths and planting dates at each trial. Phenological development, plant height, pod clearance, number of pods per plant, number of seeds per pod, hundred-seed weight and grain yield were measured.

At trial 1 the three maturity groups were planted at four plant densities (200 000, 300 000, 400 000 and 500 000 plants ha^{-1}), one row width (0.76 m) and one planting date. Maturity group had the greatest effect on phenological development, plant height, pod clearance, hundred-seed weight, and grain yield. Plant density had the greatest effect on plant height, number of pods per plant, while also affecting yield only during the 2016/17 season.

At trial 2 the three maturity groups were planted at four plant densities (150 000, 200 000, 300 000 and 400 000 plants ha^{-1}), two row widths (0.38 m and 0.76 m) and one planting date. Similar to trial 1, maturity group had the greatest effect on phenological development, plant height, pod clearance, hundred-seed weight and grain yield. Plant density had the greatest effect on plant height and number of pods per plant, while also affecting grain yield slightly during the 2017/18 season. Row width had the greatest effect on hundred-seed weight and grain yield.

At trail 3 the three maturity groups were planted at four plant densities (150 000, 300 000, 400 000 and 600 000 plants ha^{-1}), two row widths (0.30 m and 0.60 m) and at two planting dates (early/normal and late). Similar to trial 1 and 2 only, maturity group had an effect on phenological development for both planting dates. Plant height was affected by maturity group, plant density and row width at both planting dates. Plant heights for the late planting date were shorter compared to the early/normal planting date. Pod clearance was affected most by maturity group, while the effect of plant density and row width was not as profound. Between planting dates, pod clearance was slightly higher during the early/normal planting date, but this was negligible. Number of pods per plant was only affected by plant density for the early/normal planting date, while for the late planting date maturity group and row width also produced an effect. Between planting dates there were no significant difference in number of pods per plant. Hundred-seed weight was affected by both maturity group and plant density for both planting dates, while row width only had an effect during the late planting date. Hundred-seed weight was considerably higher during the early/normal planting date compared to the late planting date. Grain yield was mostly affected by maturity group during the early/normal planting date, while row width also had an effect. During the late planting date grain yield was affected by maturity group, plant density and row width. Grain yield was considerably higher during the early/normal planting date compared to the late planting date.

It can therefore be concluded that maturity group and planting dates have a great effect on grain yield. The grain yield of a late planting date is considerably lower compared to early/normal planting dates. Plant density also affects grain yield, but the effect is not as profound for an early/normal planting date, while for a late planting date the effect is greater with grain yield increasing slightly with increased plant density. Grain yield is also affected by row width with narrower rows producing greater grain yields compared to wider rows.

Keywords: Maturity group, plant density, row width, planting date, grain yield

Chapter 1

Introduction

1.1 Background

Soya bean (*Glycine max*) is considered globally to be the fourth most important food crop after wheat, rice, and maize, and is, in economic terms, the most important bean in the world (USDA, 2018). Soya bean is an annual crop and produces more protein and oil per unit of land than almost any other grain grown crop (Martin, 1988), providing one of the richest and cheapest sources of protein for humans and animals, as well as ingredients for hundreds of chemical products. Soya bean is an erect, branching, fairly easy and fast-growing crop that yields best in temperate regions (Martin, 1988).

South Africa has six main climatic regions which include the cold, temperate, hot, arid interior, the temperate as well as sub-tropical coastline. Each climatic region varies in rainfall, altitude, and temperature. The North Eastern Free State is situated in the cold interior of South Africa (South Africa's weather and climate, 2018). According to the Köppen-Geiger climate classification the North Eastern Free State is classified as warm temperate with dry winters and hot summers (Conradie, 2012). The province is situated between 23° and 29° south of the equator, which results in relatively warm summer temperatures. Because the North Eastern Free State is far from the coastline, the temperature is not kept constant by the sea, resulting in quite a large difference between day and night temperatures (South Africa's weather and climate, 2018). Winters are very cold with snow on the mountains, because of high altitudes ranging from 1200 m to 2500 m above sea level. Tendencies to late frost up until the first week of October, and early frost as soon as April are common in the North Eastern Free State, shortening the growing season length (Kotzé, 1980).

The demand of soya beans largely originated from the crushing and processing industries. Increasing demand for soya bean meal and oil is mainly a result of improved crushing capacity and rising income levels of consumers. Soya bean demand is also increasing because of the increasing demand for livestock products due to rising incomes and population, resulting in increasing demand for animal feed, especially more protein rich feed (DAFF, 2016). It is therefore important that soya bean production increases in a sustainable manner and research must be done on how this can be achieved.

Successful soya bean production depends on a variety of factors. With dryland production, rainfall is the one environmental factor that cannot be controlled. Furthermore, the occurrence of frost, and a minimum temperature required for emergence, which influences the planting date, cannot be controlled. The correct management practices and application of production inputs is of importance. These management practices and production inputs include planting certain maturity groups, planting date, plant density, row width, soil tillage, fertilization, pest (weed, insect and disease) control, harvesting, marketing and financial resources (Yada, 2011). Because of the compensation ability of soya beans, and the sensitivity to day-length, some of these inputs can have a great effect on yield (Rienke and Joke, 2005; Lee *et al*., 2008). Planting date, maturity group, plant density and row width are agronomic practices that can be adjusted in an attempt to further improve productivity. These four practices are the focus of this study.

Planting date is not always controllable. The occurrence of frost, minimum temperature required for emergence and sufficient soil moisture, as well as follow-up rainfall influences planting date. If conditions favour early planting, this results in a longer growing season, and the opposite occurs when conditions only allow planting to commence later in the season. Planting dates have a direct influence on maturity group selection. Soya beans are divided into different maturity groups depending on the average number of days to flowering (Khubele, 2015). In the North Eastern Free State, especially, where the growing season is shorter due to early frost in April, maturity group plays a vital role. Thus, when conditions favour early planting, a maturity group with a longer growing period will use the growing season more effectively than a maturity group with shorter growing period. According to J.T. Prinsloo (personal communication)[a] when conditions favour a later planting date, a maturity group with a shorter growing period will be able to complete production within the growing season, while maturity groups with a longer growing period could be negatively influenced by early frost or dry conditions during April, resulting in decreased yields.

Adjusting row width and plant density are relatively simple agronomic practices. Decreasing row width at any plant density has many advantages. Firstly, decreasing row width results in a more equidistant plant arrangement, reducing inter-row competition for water, nutrients, and light between plants (Yada, 2011). Narrower rows result in earlier canopy closure, increasing sun light interception, radiation use efficiency and grain yield (Shibles and Weber, 1966; Caliskan *et al*., 2007). Early canopy closure also decreases the amount of sun light that reaches the ground, resulting in less water being lost through evaporation and a

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decrease in the potential for weed growth (Osman, 2011). This is especially important under dryland conditions for more efficient water use. Narrow row widths also enhance soil protection, decrease water runoff and soil erosion (Mannering and Johnson, 1969). Because soya beans have such a high compensation ability, a wide range of seeding rates generally have little effect on seed yield, resulting in more or less the same yield (Lee *et al*., 2008). Different seeding rates could have different economic effects. In the case of higher seeding rates, seed cost must be taken into consideration, and in the case of lower seeding rates, the effect of hail and poor emergence percentage can negatively affect yield.

The influence which planting date, maturity group, plant density and row width have on yield, prompted the attempt to find solutions.

1.2 Objectives

The main objective was to evaluate the yield response to different maturity groups, plant densities, row widths, and planting dates.

Sub-objectives include:

- Identify the best maturity group, plant density and row width that optimize yield for different planting dates from mid-October to December.
- Identify which maturity group, plant density and row width to plant at certain planting dates to reach maximum yield within the North Eastern Free State.

Chapter 2

Literature Review

2.1 Origin, Production and Importance of Soya bean in South Africa

Soya beans were first produced in South Africa in 1903 (DAFF, 2010). At that time farmers had little or no information about soya bean production and production thus stalled. It was not until the late 1990's that production of soya beans started increasing (Dlamini *et al*., 2014). South Africa is still a small soya bean producer compared to other countries in the world, but production is rapidly increasing. The area set aside for or brought into production for soya beans demonstrates the rising importance of the crop in the country (Dlamini *et al*., 2014).

South Africa is Africa's leading soya bean producer, producing 1.17 million tons on 0.73 million hectares during the 2018/2019 season (DAFF, 2019). Over the past ten years, soya bean production in South Africa rose by 446% (by 1 258 000 tons), from 282 000 tonnes in 2007/2008 to 1.54 million tonnes in the 2017/2018 season (DAFF, 2019). The area under soya bean cultivation increased from 93 790 hectares to 787 200 hectares in the past 20 years (DAFF, 2019). Soya beans are cultivated in all nine provinces with Mpumalanga and Free State being the major producers the past five years followed by KwaZulu-Natal, Gauteng, Limpopo and North-West provinces. Soya bean production in the Northern Cape, Eastern Cape and Western Cape is confined, with the Western Cape ceasing production during the period 2012 to 2014. Mpumalanga and the Free State accounted for 42.4% and 41.2%, of the total soya bean production respectively in the 2018/2019 season (DAFF, 2019).

Soya beans are an important food legume used for food, beverages, and animal feed worldwide. It consists of 19% oil, 68% meal consisting of 36% protein, 19% insoluble carbohydrates, 9% soluble carbohydrates and 4% minerals, and 13% moisture content (Stowe, 2017). The form in which soya beans are consumed is mainly determined by the area in which it is being used (Mabulwana, 2013). In South Africa, the primary uses include soya bean meal/cake (Opperman and Varia, 2011), which is largely consumed by the livestock sector (DAFF, 2019). Even though soya beans have excellent nutritional value, a very small percentage is used by humans (Joubert and Jooste, 2013). Human consumption is only 25% while 60% is used for animal feed. Within the animal feed sector, the poultry industry is by far the largest consumer of soya beanderived protein (Joubert and Jooste, 2013). Soya beans are consumed in South Africa by humans in the form of over-the-counter food such as soya sauces, soups, and other nutritious breakfast foods such as yoghurt and flavoured soya milk products (Dlamini *et al*., 2014). Sustainable soya bean production is therefore important in order to sustain the growing demand.

2.2 Description

Soya bean is a legume crop that belongs to the botanical family Leguminosae or Fabaceae. The soya bean plant has a plant height ranging between 30 cm and 200 cm, depending on the variety, with erect and hairy stems (Fehr and Caviness, 1977; Ngeze, 1993). Soya beans have two types of growth habit *viz*. determinate and indeterminate. Determinate genotypes generally grow shorter and produce fewer leaves in comparison to indeterminate genotypes which generally grow into taller plants and produce more biomass (Fehr and Caviness, 1977; Ngeze, 1993). Soya beans have a typical allorhizic root system with two root types namely: a tap root and a large number of lateral roots that can grow as deep as 150 cm, but generally the most active root growth is found in the top 15-20 cm soil (Gray, 2006).

Generally, the stems, leaves and pods are covered with fine brown or white to grey hairs. The leaves are compound with three leaflets. They are alternate, trifoliate with ovate leaflets and a short peduncle. The flowers develop as short axillary with terminal racemes in clusters of 8 to 16 flowers, and are white, purple, or pink. The flowers are self-pollinated and completely self-fertile. The fruit are called pods that are hairy, broad, straight, flattened or cylindrical, grown in clusters of three to five, each between three to ten centimetres long, containing one to four seeds that are usually coloured yellow, black or green. The hull of the mature pod is hard, water resistant and protects the cotyledons and hypocotyls from damage (Ngeze, 1993; Rienke and Joke, 2005; Gray, 2006).

2.3 Growth and development

Fehr and Caviness (1977) identified that there are major differences in plant development between indeterminate and determinate soya bean varieties. Within indeterminate varieties when flowering begins, these varieties have generally achieved half of their final plant height, where after flowering, pod-set and pod fill as well as branch production continues. Flower and pod development occur at different stages depending on where the nodes are located on the plant. The pods that are produced at the bottom of the plant are more advanced compared to the upper part of the plant. The top of the plant generally produces smaller leaves and the stems do not end with a terminal raceme, or the raceme is smaller with only a few pods produced at the terminal end (Fehr and Caviness, 1977).

Determinate varieties are generally smaller, and little growth commences after flowering. Flowering occurs relatively simultaneously throughout the plant. Pod and seed development occur at the same time. Determinate varieties produce a terminal leave at the top of the main stem with the same size as that of the lower leaves, while a terminal node is produced on the main stem with a long flowering raceme. The terminal raceme produces several pods (Fehr and Caviness, 1977).

Fehr and Caviness (1977) defined the vegetative and reproductive growth stages of soya beans. The determination of these stages requires node identification. Nodes rather than leaves are used to identify each stage because nodes are permanent, while leaves can drop throughout the season. The vegetative growth stages are described from plant emergence (VE). After emergence, the cotyledon stage (VC) occurs. This is when the two unifoliate leaves are unfolded sufficiently so the leaf edges do not touch. After the VC stage, nodes are counted to determine the vegetative stages beginning with the unifoliolate nodes (V1) that are technically two separate nodes, but are counted as one because they occur on the same position and time on the main stem. Following V1, each node with fully developed trifoliate leaves above the unifoliolate nodes are counted. If there are seven nodes with fully developed trifoliolate leaves above the two unifoliolate nodes the vegetative growth stage will be classified as V8.

The reproductive growth stages are based on flowering, pod and seed development, and plant maturity. The first reproductive stage (R1) is at the beginning of bloom/flowering, when one open flower is found at any node on the main stem. After R1, full bloom occurs (R2), which is when an open flower is found at one of the two uppermost nodes on the main stem with a fully developed leaf. R1 and R2 occur simultaneously in determinate varieties because flowering begins at the upper nodes of the main stem. R1 and R2 generally occur three days apart for indeterminate varieties, with flowering beginning at the lower part of the main stem. The next stage is the beginning of pod formation (R3), when pods are 5 mm long at one of the four uppermost nodes on the main stem with a fully developed leaf, followed by full pod (R4) when pods are 2 cm long at one of the four uppermost nodes on the main stem with a fully developed leaf. Beginning seed (R5) occurs when seeds are 3 mm long at one of the four uppermost nodes on the main stem with a fully developed leaf. Full seed (R6) occurs when a pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf.

After seed development maturity occurs with beginning maturity (R7), when one normal pod on the main stem has reached its mature pod colour (brown or tan), and full maturity (R8) when ninety-five percent of the pods that have reached their mature pod colour. Five to ten days of drying weather are required after R8 before soya beans exhibit less than fifth teen percent moisture and are ready for harvesting (Fehr and Caviness, 1977).

2.4 Plasticity and compensation ability

According to the Oxford dictionary the definition of plasticity is the adaptability of an organism to changes in its environment or differences between its various habitats. Soya bean has the ability to regulate growth in response to various environmental and agronomic factors to produce maximum yields (Board, 2000). According to Carpenter and Board (1997) yield is considered as a function of four basic factors of yield components, which include the number of pods per plant, number of seeds per pod, seed weight and the number of plants per area. The agronomic factors that have an influence on the growth impacting soya bean yield are plant density, row width and planting date.

Individual plant growth and development are directly influenced by the space available to plants; thus, plant density and row width have a direct influence on this available space for growth and development (Kirby and Faris, 1970; Yigezu, 2014). Studies conducted on the response of soya beans to various plant densities showed that soya bean plants have the ability to compensate over a wide range of plant densities (Lueschen and Hicks, 1977; Osman, 2011; Vonk, 2013). Soya bean plants compensate for low plant densities by producing more branches and pods per plant (Lueschen and Hicks, 1977; Carpenter and Board, 1997) hence producing more seeds per plant, resulting in yield remaining relatively constant over a wide range of plant densities. At low plant densities soya bean plants also have the ability to increase seed weight (Ferreira *et al*., 2018).

Row width influences the available space for growth and development of soya bean plants in two main ways. Firstly, the available space between rows are affected by the row width; for example, 0.38 m rows compared to 0.76 m rows have less space between rows for growth and development. Secondly, the intra row spacing for two row widths planted at the same plant density will differ; for example, 0.38 m rows compared to 0.76 m rows will have a greater intra row spacing, hence more available space within each row. According to Cox and Cherney (2011) 0.19 m rows out yielded 0.38 m and 0.76 m by 0.25 t ha^{-1} and 0.51 t ha^{-1}, respectively. De Bruin and Pedersen (2008b) conducted row width and plant density experiments concluding that reduced row width (0.38 m vs. 0.76 m) is more economically significant than increasing plant density in response to increasing yield. The positive effect on yield to reduced row widths are primarily due to more equidistant plant spacing, resulting in less intra-row competition for sunlight, water and nutrients between plants. More equidistant plant spacing due to narrow row widths, results in more space for plant growth and development, resulting in turn more branches and pods per plant, hence increasing yield (Shibles and Weber, 1965; Yada, 2011).

Soya bean growth and development are largely influenced by planting date, showing great plasticity in plant development stages due to the plant's sensitivity to photoperiod. Many studies done on planting dates concluded that early planting produced greater yields compared to late planting, merely because of a longer growing season and more favourable conditions hence the plant producing more branches, pods per plant and seeds per pod (Beaver and Johnson, 1981; Pedersen and Lauer, 2003; Robinson *et al*., 2009). According to Robinson *et al*., (2009) soya bean plants can compensate for late planting dates by increasing seed weight, because fewer pods are produced. This does however, not always occur, especially if conditions are not favourable.

In summary, soya beans have the ability to compensate for various factors such as plant density and row width, and to lesser extent planting date, by adjusting plant growth and development in ways such as increased branch development, number of pods per plant, number of seeds per pod and seed weight.

2.5 Climate requirements/environmental factors

Soya bean development and yield can be influenced by environmental conditions such as temperature, photoperiod, precipitation and a combination of these factors (Fehr and Caviness, 1977; Kumudini *et al*., 2007; Chen and Wiatrak, 2010).

2.5.1 Photoperiod and temperature

Soya bean is photoperiod sensitive and within soya bean species there are varieties that react differently to photoperiod. The different varieties are classified as long day, short day, and neutral day plants (Borget, 1992). However, soya bean is typically described as a short-day plant (Rienke and Joke, 2005; Yigezu, 2014). Soya bean has a relatively short growth duration, primarily due to day length sensitivity. Soya bean development are regulated from emergence up to maturity (Han *et al*., 2006). This affects the total length of the vegetative growth stage, flower induction, pod and seed development and maturity (Norman *et al*., 1995). Most varieties require 10 – 12 h (short photoperiod) of daily darkness to advance from vegetative growth stage to reproductive growth stage. Short photoperiod also promotes leaf senescence, while long photoperiod (15-18 h) during R1 to R5 growth stages delays leaf senescence and seed maturity of some late maturing cultivars (Han *et al*., 2006). A long photoperiod also retards reproductive development while a short photoperiod enhances it. Planting dates have a significant effect on how soya bean reacts to photoperiod. Early planting exposes soya bean plants to a longer photoperiod after flowering, resulting in an extended duration, from R3 to R6, increasing the total number of seed per plant (Kantolic and Slafer, 2005). Planting date plays a major role in the development of soya bean in terms of the plant's reaction to photoperiod. According to Egli and Bruening (2000), delayed planting resulting in shorter photoperiod during reproductive growth stages is the primary reason for decreased grain yield, especially for longer growing varieties. Early planting can result in premature flowering because of an inadequate photoperiod (Board and Hall, 1984). Delayed planting can also reduce the number of days to emergence and flowering, resulting in vegetative and reproductive growth stages falling in less favourable environmental conditions (Egli and Cornelius, 2009).

Temperature has a major effect on soya bean plant growth, development and grain yield (Fehr and Caviness, 1977). An increase or decrease in temperature may have a negative or positive effect, depending on the range of temperatures (Bellaloui *et al*., 2011) as well as available soil water. Low temperature retards seedling emergence and leaf development as well as reproductive growth stages, while higher temperature enhances it (Fehr and Caviness, 1977). The minimum temperature requirement for soya bean at which development can take place is 10°C (base temperature), the optimum 22°C and the maximum about 40°C. Soil temperature must be above 10°C for germination to occur, while temperatures between 15°C and 40°C are suitable for germination with the optimum being 30°C (Rienke and Joke, 2005). The optimum temperature range for growth is considered between 23-25°C according to Addo-Quaye *et al*., (1993). The effect temperature has on soya bean and the intensity thereof depends on time of occurrence, and in which development growth stage the soya bean was. Cooler temperature early in the season combined with an early planting date can reduce plant development and retard flowering (Fehr and Caviness, 1977). Higher daily temperature during flowering, pod-set, and seed-fill growth stages decreased photosynthetic rates and seed growth (Gibson and Mullen, 1996). Temperature effect on yield also varies across different soya bean maturity groups (Hu, 2013). Thus, the effect of temperature on soya bean production depends on a range of factors including planting date, photoperiod sensitivity between varieties, and different maturity groups.

2.6 Maturity group and planting date

Maturity groups (MG) differ in many ways such as number of days to flowering, plant height, number of branches per plant, number of pods per plant and number of seeds per pod (Khubele, 2015). Soya beans are also sensitive to photoperiod, which means that the number of days to flowering is influenced by day length and temperature. Because soya beans have different maturity groups, with different numbers of days to flowering, the planting date will affect each maturity group differently (Osman, 2011). Planting date is the single most determining factor effecting the maturity group's yield and is possibly one of the most influential cultural/agronomic practices of soya bean production (Vonk, 2013). For this reason, these two factors are discussed as linked. Row width and plant density also influence each maturity group's yield ability and will be discussed later (section 2.7 and 2.8).

In the North Eastern Free State, planting date is influenced by different factors each year. Planting date is influenced by the last incidence of frost at the start of the growing season and minimum temperature required for emergence. Because the North Eastern Free State has a cooler climate, the occurrence of late frost and cold temperatures early in the growing season are common (Kotzé, 1980). Sufficient and well-distributed rainfall are also necessary for favourable emergence and optimum stand. Economically competitive crops, such as maize (*Zea mays* L.) also influence the planting date of soya beans, especially in the North Eastern Free State. Maize is ideally planted from early November, mid-November till mid-December in the North Eastern Free State. Soya beans can be planted earlier from mid-October. For this reason, farmers will plant their soya beans before maize. This results in a shorter period available for soya bean planting, and this period also falls in the earlier planting season. Thus, according to J.T. Prinsloo (personal communication)[a], many factors determine the planting date of soya beans.

In the North Eastern Free State, normal -considered as early in this study- planting date is considered as from 15 October till 15 November, and late planting date after 15 November till December. Planting dates after 15 December are not recommended in the North Eastern Free State. The growing season length is usually determined by the first frost or a late summer drought. This usually occurs mid-April, which vary from year to year (J.T. Prinsloo – personal communication)[a].

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Research conducted on the effects of maturity group and planting date on soya bean yields was mostly done in the United States of America (U.S.A.). Unfortunately, scientific data in South Africa is scanty. The U.S.A.-based results revealed that where early/normal planting was considered from April to mid-May, and late planting after mid-May till June, MG 5 yielded higher yields planted early (1 April), than those planted later (after April 1). MG 4 however, maintained high yields for all planting dates (Pedersen and Lauer, 2004; Egli and Cornelius, 2009). MG 4 also out yielded MG 5 and MG 6 for late planting dates (Salmerón *et al*., 2015). The reason why typical yield reduction occurs when planting dates are delayed, is because of a shortened growing season, less optimum temperatures, and reduced sunlight interception (Salmerón *et al*., 2015). Because longer growing maturity groups need a longer growing season, the optimum planting date window is shorter and earlier in the season with shorter growing maturity groups having a longer planting date window, and can thus be planted later in the season. Similar research in the U.S.A. on soya bean planting dates showed that late planting dates result in significant yield losses (De Bruin and Pedersen, 2008a). In other studies, planting soya beans after 27 May resulted in a rapid decline in grain yield regardless of the maturity group (Chen and Wiatrak, 2010). Later planting dates also resulted in shorter vegetative and reproductive stages (Chen and Wiatrak, 2010). Chen and Wiatrak (2010) noted that there was a significant interaction between planting date and maturity group in yield for MG 4 to 7.

Similarly, late April planting dates resulted in higher yields than when planting early May, but late May planting still produced lower yields than those in late April and early May (Robinson *et al*., 2009). Carter and Boerma (1979) reported that there were significant interactions between genotype, planting date and row spacing regarding yield, and concluded that there is need for further research.

In a study with different maturity groups and planting dates, Heatherly (1999) reported that early planting in April and the use of MG 3 to 5 cultivars are a successful strategy to avoid late summer drought, producing higher yields compared to MG 5 to 6 cultivars planted in May and June. MG 3 and 4 planted in March and April could lead to premature flowering and reduced radiation interception compared to maturity groups with longer days to flowering. The conclusion is that MG 3 and 4 cultivars may benefit more from later planting dates than longer growing maturity groups, and longer growing maturity groups may benefit more from early planting dates compared to MG 3 and 4 (Salmerón *et al*., 2015). The reason why early maturity groups may benefit more from a late planting date compared to later maturity groups is because an early maturity group will be able to complete the reproductive growth stage before a late summer drought or frost, compared to a late maturity groups. With an early planting date, a later maturity group will optimally use the whole season for vegetative and reproductive growth, resulting in higher yields than an early maturity group, which only makes use of a certain period of the growing season. Research, which proves this information, was done by Salmerón *et al*., (2014) who noted that MG 4 and 5 cultivars had the greatest probability (80%) of achieving higher yields at early planting dates ranging from 20 March to 31 May compared to MG 3. With late planting dates, MG 3 and 4 have the greatest probability (62%) of achieving these greater yields. According to Chen and Wiatrak (2010), a late planting date can reduce the total length of the vegetative period, flowering, pod-set, and to a lesser extent, seed-fill period. They conclude that later maturity groups, with longer vegetative and reproductive stages, may be affected more than early maturity groups, resulting in lower yields compared to early maturity groups.

Although numerous studies were done on the response of soya bean yield to planting date, many of these studies were done in different countries, under different conditions and locations. There are thus several factors justifying the need to conduct further research under local conditions, and with maturity group cultivars that are recommended for the North Eastern Free State.

2.7 Plant density

The relationship between plant density and row width and the effect it has on yield is explained with two general concepts. The first concept posits that maximum crop yield can only be achieved if a crop community is able to produce sufficient leaf area during the vegetative growth stage for maximum light interception during reproductive growth (Shibles and Weber, 1965). The second concept states that equidistant plant spacing minimizes interplant competition, maximizing yield (Wiggans, 1939).

Many studies were conducted, focusing on the optimum plant density for soya beans, in particular at different maturity groups, row widths, planting dates and climates. The studies showed that there is no single one specific optimum plant density. De Bruin and Pedersen (2008b) reported that 194 000 to 291 000 seeds per hectare were the optimum plant density for wider rows (76 cm), and 157 000 to 212 000 seeds per hectare for narrow rows (38 cm). Herbert and Litchfield (1984) reported that the optimum plant density for a specific cultivar was 656 000 plants per hectare, and for another cultivar, 680 000 in the North east of the U.S.A. Studies conducted at different climates resulted in different optimum plant densities.

Some studies revealed that there is no significant increase in yield with increased plant densities from 260 200 to 520 400 seeds per hectare (Pedersen and Lauer, 2002). The reason soya beans show little or no significant yield response over a wide range of plant densities is because of the compensation mechanism and plasticity of soya beans (Lee *et al*., 2008). Soya beans have the ability to produce fewer or more seeds per plant when plant densities are high or low, respectively (Lee *et al*., 2008). The soya bean's compensatory mechanism also regulates branch production and development according to available space and favourable conditions for growth (Kirby and Faris, 1970). Individual soya bean growth and development is directly influenced by the available space between neighbouring plants (Kirby and Faris, 1970).

Looking at the results of different studies done over a wide range of conditions, many factors can influence optimum plant density. Different environments, management systems and cultivars have an influence on the optimum plant density (Mellendorf, 2011). In a study conducted by Ball *et al*., (2001), interaction between planting date and plant density showed that higher plant densities can partially compensate for decreased yield with late planting. In the same study, early planting produced adequate pods at low plant densities, whereas late planting required more plants for the same number of pods. Ball *et al*., (2001) stated that early planting had more vegetative growth, resulting in more fertile nodes and pods produced to compensate for a lower plant density.

A study done on the interaction between row width and plant density showed that there was a significant interaction, with narrow row widths requiring higher plant densities. Herbert and Litchfield (1984) reported increasing plant densities from 250 000 to 800 000 plants per ha increased yield by 27% for narrow row widths of 25 cm, and for wider row widths of 75 cm showed a 16% yield increase.

When evaluating these studies and other literature, it is clear that optimum plant density will vary between regions, and different conditions such as different planting dates, row widths and maturity groups. It is also apparent that soya beans have the ability to compensate over a wide range of plant densities to reach maximum yield. Increased plant densities result in increased seed costs. It is normal practice to plant with a slightly higher plant density than planned for, to ensure a good stand and for compensation in the event of hail. With increased seed costs, this practice has also resulted in a greater cost to the producer. With soya bean yields not differing significant between wide ranges of plant densities, it will be more significantly economical for producers to plant lower plant densities, hence the same results are generally found in the North Eastern Free State. Further research and field studies must be done in the North Eastern Free state to identify an optimum plant density, or a certain range of plant densities for optimum yields under different conditions such as row widths, planting dates and maturity groups.

2.8 Row width

Many studies were conducted on the effect of different row widths on soya bean yield. However, there are mixed reports, but in general the overall understanding is that narrow rows tend to produce higher yields compared to wider rows (Vonk, 2013). Wide rows -76 cm and 91 cm width planters- are used for maize production in the North Eastern Free State. Therefore, in practise, farmers use the same planter for maize and soya bean production. Wider rows also allow post-emergence herbicide application with less damage to the crop. Spraying can also occur later in the season when needed because tractors and sprayers can still enter the field, and it is also believed that wider rows increase air flow between rows, which decrease the development of a favourable micro climate for the fungus Sclerotinia (*Sclerotinia sclerotiorum)*.

The most common reason or answer for narrow rows producing higher yields than wider rows is that narrow rows have increased light interception (Caliskan *et al*., 2007). The total amount of light a crop intercept is a simple function of plant density and row spacing (Charles-Edwards and Lawn, 1984). Soya beans planted in narrow rows form a leaf canopy more rapidly than wider rows, achieving full light interception earlier in the growing season and with a lower leaf area index, increasing the yield potential (Board and Harville, 1992). Rapid canopy closure also enhances weed management, increase plant establishment and decreased evaporation (Hoeft *et al*., 2000). Taylor (1980) also states that rapid canopy closure can increase transpiration, leading to increased loss of stored water which leaves less available water during critical periods such as pod fill. Narrow rows also result in more equidistant plant arrangement, reducing inter-row competition between plants for water, nutrients and light (Yada, 2011), increasing yield.

According to Bullock *et al*., (1998) soya bean yield increases with a decrease in row width. Narrow rows (38 cm) out yielded wider rows of 76 and 114 cm by 8 and 20% respectively, while 76 cm out yielded 114 cm by 12%. A study done by De Bruin and Pedersen (2008b) reported that narrow rows out yielded wider by 284 kg ha^{-1} (6.2%). In contrast, some studies revealed that there was no yield response to narrow rows (Pedersen and Lauer, 2003).

Many studies contend that the increased yield obtained by narrow rows are substantially higher with short or early maturing soya beans (Costa *et al*., 1980). According to James *et al*., (1996) higher yields were obtained for early maturity groups with narrow rows and high plant densities. Studies have shown that the response to narrow rows is limited by lower than normal rainfall (Taylor 1980). In severe water stress conditions, narrow rows can lead to lower yields. The reason for this could be because of rapid canopy closure and increased water use early in the season, resulting in less water for critical stages such as pod filling later in the season (Alessi and Power, 1982).

According to Boquet (1990) narrow rows cannot fully compensate for late planting but yield losses due to late planting can be decreased by as much as 16% by using narrow rows instead of wider rows. In most of the literature, there are many examples of research which contends that planting narrow rows produces higher yields. Increases in yields vary each year and under different conditions, but in most of the studies done on row width, narrow row widths produced higher yields than wide rows (Costa *et al*., 1980; Board and Harville, 1992; James *et al*., 1996; Pedersen and Lauer, 2003; Vonk, 2013).

Farmers/producers constantly ask questions on the selection of maturity groups, what plant densities and row widths combinations are the most suitable as well as what the effect of planting date on yield are. These questions prompted this study and the attempt to find answers.

Chapter 3

The Influence of maturity group and plant density on the growth, yield components and yield of soya beans (*Glycine max*) in the North Eastern Free State between Vrede and Memel

3.1 Introduction

Successful soya bean production depends on a variety of factors. Some of these factors are uncontrollable (environmental factors), and some are controllable (agronomic inputs). Agronomic inputs include selection of the correct maturity group, plant density, planting date, row width, fertilizer application, soil tillage, weed management, insect, and disease control (Yada, 2011).

Many factors have an influence on which maturity group is best suited for a specific cropping season and environment. The single most import factor for determining which maturity group is best suited is length of the growing season. Firstly, length of the growing season is influenced by planting date, which is in turn is influenced by the first sufficient and follow-up rainfall as well as the minimum temperature required for germination and rapid emergence. Secondly, the occurrence of frost, both early in the season and at the end of the season. The North Eastern Free State is commonly known to be cooler resulting in shorter growing seasons due to the incidence of late frost up until October, and early frost as soon as April (Kotzé, 1980). Maturity groups have different growth lengths, therefore, the choice in maturity groups is critical in utilizing growing season optimally, resulting in satisfactory yields (Khubele, 2015).

Plant density is widely debated in soya bean production due to different responses within different environments and agronomic practices. Row width, maturity group, planting date and climate are known to influence plant density, but it is also widely known that soya beans have a high compensation ability, resulting in little yield differences within a wide range of plant densities (Lee *et al*., 2008). Studies on soya bean plant density resulted in an array of recommendations. No single recommendation is proposed, and any recommendation seems to be site specific. For example, De Bruin & Pedersen (2008b) reported that 194 000 to 291 000 plants per hectare were optimum for a 0.76 m row width and 157 000 to 212 000 plants per hectare for a 0.38 m row width. Herbert & Litchfield (1984) reported that the optimum planting density for a specific cultivar was 656 000 plants per hectare, and for another cultivar 680 000 plants per hectare in the North east of the U.S.A. Pedersen and Lauer (2002) reported that there was no significant difference in yield between 260 200 and 520 400 seeds per hectare. According to studies done in South Africa by van Wyk (2000) the optimum planting density for 0.76 m rows are 200 000 to 300 000 plants per hectare.

Considering the studies done over a wide range of conditions and knowing that many factors influence selection of maturity group as well as plant density, it is critical to choose the correct combination of each for a specific environment. The objective was to evaluate soya bean response to different maturity groups at different plant densities in the North Eastern Free State.

3.2 Materials and Methods

3.2.1 Experimental site

Two field experiments were conducted on a farmer's field during the 2016/17 and 2017/18 cropping season. The field is located in the North Eastern Free State between Vrede and Memel. Geographically, the experimental site was situated at 1 773 m above sea level on latitude -27.634146 and longitude 29.362426. Rainfall data drawn from a rain gauge on the experimental sites during the two growing seasons are summarized in Table 3.1. The chemical and physical properties of the soil are summarized in Table 3.2.

Table 3.1 Rainfall (mm) for the 2016/17 and 2017/18 cropping seasons at the experimental sites between Vrede and Memel

	Rainfall (mm)								
Season	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
2016/17	17	86	194	139	121	167	10	0	6	**740**
2017/18	6	47	83	172	125	71	158	29	30	**721**

Table 3.2 Chemical and physical properties of the experimental sites between Vrede and Memel

	Cropping season	
Physical properties	**2016/17**	**2017/18**
Clay (%)	32	30
Density (g cm^{-3})	0.92	0.91
Chemical properties		
pH (KCl)	4.9	4.6
Nutrients (mg kg^{-1})		
P (Bray 1)	9.2	4.6
K (NH_4OAc)	227	181.4
Ca (NH_4OAc)	2449	2089
Mg (NH_4OAc)	636.6	614.1
Na (NH_4OAc)	5.9	7
S (NH_4OAc)	29.73	52.05
Exchangeable acids	0	0.21
Acid saturation (%)	0	1.29
Ca/Mg	2.35	2.08
(Ca+Mg)/K	24.65	33.36
CEC ($cmol_c kg^{-1}$)	18.19	16.18

* Soil sample taken at a depth of 0-20 cm

3.2.2 Experimental Design and Treatments

The experimental design was a factorial experiment laid out in a split-plot design with three replications. Treatments included three cultivars (maturity groups) and four plant densities. The main plot factor was maturity group (MG) and the sub-plot factor plant density (PD). The three cultivars used in this experiment were SSS 4945 tuc (MG 4.5), SSS 5449 tuc (MG 5) and SSS 6560 tuc (MG 6). MG 4.5 is classified as a short, MG 5 as a medium, and MG 6 as a medium-long maturity group. Other cultivar characteristics are summarized in Table 3.3. The four planting densities represented a plant stand of 200 000, 300 000, 400 000 and 500 000 plants ha^{-1}.

Each plot consisted of 12 sub-plots, each 5 m long with 1 m paths between sub-plots consisting of four planting rows. The planting rows were spaced 0.76 m apart making one sub-plot 3.04 m wide. In total there were 3 main plots with 36 sub-plots. Each main plot measured 74 m x 3.04 m and each sub-plot 5 m x 3.04 m. Finally, the total area designated for the experiment measured 674.88 m^2 (74 m x 9.12 m).

Table 3.3 Cultivar characteristics representing the three (3) maturity groups (MG)

Characteristic	Cultivar		
	SSS 4945 tuc	**SSS 5449 tuc**	**SSS 6560 tuc**
Maturity Group	4.5	5	6
Growth Type	Semi-indeterminate	Indeterminate	Indeterminate
Growth Period	Short	Medium	Medium to long
Days to flowering	59	63	70
Days to harvest (moderate – cooler areas)	133 – 144	139 - 157	155 - 171
Plant Height (cm)	65	90	90
Pod clearance (1=high, 9=low)	5	2	2
Standability	Excellent	Good	Good
Shattering resistance	Resistant	Good	Good
Seed Density (Plants/ha^{-1})			
Dryland- Cooler	320 000 - 360 000	300 000 - 340 000	280 000 - 300 000
Dryland- Warmer	380 000	340 000	320 000
Row width/ Thousand seeds (‘000)	76 cm 52 cm 38 cm 320 340 360	76 cm 52 cm 38 cm 300 320 340	91 cm 76 cm 52 cm 38 cm 280 280 300 300

3.2.3 Agronomic practices and management of the experimental site

The experiments were conducted under dry land conditions over two cropping seasons (2016/17 and 2017/18) on two different locations on the farm. The preceding crop for both season’s experimental sites was maize (*Zea mays* L.) on a no-till system. Planting dates were 26 October 2016 for the 2016/17 cropping season and 29 November 2017 for the 2017/18 cropping season. The planting process was done with a 12-row planter suited for planting soya beans at variable/different planting densities by adjusting planter gears. Each maturity group consisted of four (4) rows and only the middle two (2) rows were used to collect data. Desired planting densities were obtained by adjusting the planter’s gears. The experimental site was fertilized according to best agronomic farm practices. Fertilizer was broadcasted before planting with a compound fertilizer 1:1:2(20) at 200 kg ha^{-1}. Seeds were inoculated with *Bradyrhizobium japonicum* inoculant before planting. Weeds were sprayed with Roundup PowerMax at a rate of 1.5 L ha^{-1} (540 g a.i. L^{-1}) six (6) weeks after planting.

At harvest, each sub-plot was manually harvested, each plant was pulled by hand and transported from the field in poly propylene bags. Plants were threshed mechanically, moisture content determined, and yields adjusted to a 12.5% moisture content.

3.3 Data Collection and Measurements

3.3.1 Phenological development and Growth parameters

a. Phenological development: Number of days from plant to 50% flower initiation (Plant-R1), flower initiation to incipient seed-filling (R1-R5), incipient of seed-filling to physiological maturity (R5-R8) and total growth period (Plant-R8).

b. Days to 50% flower initiation: Days to flower initiation (R1 – when 50% of all plants have an open flower at one of the two upper most nodes on the main stem with a fully developed leaf) was recorded as the number of days from plant up until the R1 stage for each sub-plot.

c. Reproductive growth stage: The stage of reproductive growth was recorded each week from flower initiation (R1) up until physiological maturity (R8) for each sub-plot.

d. Plant height (cm): Plant height of three plants for each sub-plot was measured on a weekly basis up until physiological maturity. Plant height was measured from the soil surface to the highest natural growth point of plants. Only the final plant height will be discussed.

e. Pod clearance (cm): Pod clearance of three plants for each sub-plot was measured before harvesting after physiological maturity. Measurements were taken from the soil surface to the lowest point of the natural hanging pod.

3.3.2 Yield and yield components

a. Number of pods per plant: For each sub-plot, a total of ten plant pods were sampled and counted after harvest.

b. Number of seeds per pod: Number of seeds per plant was counted and divided by the number of pods to determine the number of seeds per pod.

c. Hundred-seed weight: A hundred-seeds were counted from the harvested grain and weighed. The weight was adjusted to a moisture content of 12.5%.

d. Grain yield: Grain yield for each sub-plot was harvested and converted to ton per hectare after moisture content was adjusted to 12.5%.

3.3.3 Statistical analysis

Data was analysed using the statistical program SAS version 9.2® (SAS Inst., 1992). Treatment means were separated using Tukey's least significance difference (LSD) test at a 5% level of significance.

3.4 Results and Discussion

Analysis of variance indicated that data from the 2016/17 and 2017/18 cropping seasons was not homogeneous, most probably as a result of climatic differences, hence the two cropping seasons will be discussed separately.

A summary of the analysis of variance evaluating the effect of maturity group and plant density on soya bean plants is provided in Table 3.4. Only maturity group significantly affected the number of days to a specific development stage (plant to R1, R1 to R5 and R5 to R8) and total growth period. Either main effect or the interaction thereof had no significant effect on the number of seeds per pod. Plant height was equally influenced by maturity group and plant density, while maturity group influenced pod clearance more than plant density. Number of pods per plant generally decreased with increasing plant densities, while maturity group had no significant effect on the number of pods per plant. Plant density had no influence on the hundred-seed weight, while maturity group had a significant influence. Grain yield was significantly influenced by both maturity group and plant density.

Table 3.4 Summary of analysis of variance indicating the effect of treatment factors on measured plant parameters

Treatments	Days to specific development stage								Growth parameters				Yield components and yield							
	Plant-R1		R1-R5		R5-R8		Total growth period		Plant height		Pod clearance		Number of pods per plant		Number of seeds per pod		Hundred-seed weight		Grain yield	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
Maturity group (MG)	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	ns	ns	*	*	ns	*
Plant density (PD)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	*	*	*	ns	ns	ns	ns	*	ns
MG X PD	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	*	ns	ns	ns	ns	*	*
CV %	1.24	0.71	2.27	1.45	1.07	1.56	0.33	0.22	2.76	2.05	7.35	5.18	17.45	22.95	4.68	4.78	23.98	21.76	10.05	8.73

ns – not significant
*** - P ≤ 0.05**
CV – coefficient of variance

3.4.1 Phenological development

Discussion will include the following: Number of days from plant to 50% flower initiation (Plant-R1), flower initiation to inception seed-filling (R1-R5), inception of seed-filling to physiological maturity (R5-R8) and total growth period.

3.4.1.1 2016/17

Analysis of variance indicated that maturity group (MG) was the only factor that significantly influenced the number of days for each of the developing stages *viz*. plant-R1, R1-R5, R5-R8, and total growth period (Table 3.4).

There were highly significant differences between maturity groups for the number of days to R1 growth stage. MG 4.5 only took 49 days to reach the R1 growth stage, while MG 5 and MG 6 took 56 and 70 days, respectively. MG 4.5 was ten (10) and MG 5 seven (7) days quicker than the average recommendation for each cultivar (Table 3.5). The number of days from R1 to R5 also produced highly significant differences with MG 4.5 and MG 6 that both took 28 days, significantly less than MG 5 with 35 days. The number of days from R5 to R8 took MG 4.5 and MG 6 the same time with 56 days, significantly more than MG 5 with 28 days. There were also highly significant differences for the total growth period. MG 4.5 took 133 days to reach physiological maturity, significantly less than MG 5, which took 140 days, while MG 6 took 154 days, significantly longer than MG 5 and MG 4.5. These results (days to harvest) also corresponded to cultivar information (Table 3.3), taking into consideration the dry-off period of 7 to 10 days, depending on weather conditions, which needed to be added to the total growth period before harvest could commence.

Table 3.5 The effect of maturity group on the number of days to flower initiation (R1), seed-fill (R1-R5), physiological maturity (R5-R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant to R1**	**R1 to R5**	**R5 to R8**	
4.5	49	28	56	133
5	56	35	28	140
6	70	28	56	154
MG $_{LSD\ (\leq 0.05)}$	1.9	1.8	1.51	1.24

3.4.1.2 2017/18

Similar to the 2016/17 cropping season, maturity group once more was the only factor that influenced the number of days for each of the developing stages *viz*. plant-R1, R1-R5 and R5-R8, and total growth period significantly according to the analysis of variance (Table 3.4).

There were highly significant differences between maturity groups for the number of days to R1 growth stage. MG 4.5 took 63 days to reach the R1 growth stage, while MG 5 and MG 6 took 91 days (Table 3.6). This was 4, 28 and 21 days longer than the recommended 59, 63 and 70 days for MG 4.5, MG 5 and MG 6, respectively (Table 3.3). The number of days from R1 to R5 also produced highly significant differences with MG 4.5 taking 28 days, significantly less than MG 5 and MG 6, both with 35 days. The number of days from R5 to R8 took MG 4.5, and MG 6 the same time with 42 days, significantly more than MG 5 with 28 days. There were also highly significant differences for the total growth period. MG 4.5 took 133 days to reach physiological maturity, significantly less than MG 5, which took 154 days, while MG 6 took 168 days, significantly longer than MG 5 and MG 4.5. The results of MG 4.5 corresponded to that of the cultivar characteristics. However, for MG 5 and MG 6 the total growth period was about a week longer, taking into consideration the dry-off period (7-10 days) before harvest could commence (Table 3.3). Nearly the same trend occurred during the two cropping seasons although MG 5 and MG 6 had a slightly longer growing season (2017/18) compared to the first cropping season (2016/17).

Table 3.6 The effect of maturity group on the number of days to flower initiation (R1), seed-fill (R5), physiological maturity (R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant to R1**	**R1 to R5**	**R5 to R8**	
4.5	63	28	42	133
5	91	35	28	154
6	91	35	42	168
MG $_{LSD\ (\leq 0.05)}$	1.51	1.24	1.51	0.87

This study is in agreement with Yigezu (2014) who reported that the main effect of maturity group showed significant effects on the number of days to flower initiation and physiological maturity. Kumagai and Takahashi (2020) reported that maturity group significantly affected the number of days to full bloom (R2), beginning seed (R5 and beginning maturity (R7) as well as the total growth period. Abubaker (2008) also reported that maturity group affected all development stages until physiological maturity significantly, while plant density had no significant effect on the number of days to flower initiation. The differences in number of days to each development stage and the total growth period between cropping seasons and maturity groups confirms the variability and adaptability of soya beans, due to different growing conditions (temperature and photoperiod-planting date) between seasons. In contrast, Turk *et al*., (2003) reported that a higher plant density decreased the number of days to flower initiation. Data from this study revealed that plant density had no effect on crop development.

The reason for the significant differences in the number of days to specific development stages between maturity groups might be the fact that the vegetative and reproductive stage in soya beans are a varietal characteristic and that soya bean varieties react differently to day length, which is controlled by the specific maturity group's genetics (Borget, 1992; Han *et al*., 2006; Fehr and Caviness, 1977). According to seed company's indications for each maturity group, there are significant differences in the number of days to flower initiation and physiological maturity, confirming the results obtained.

3.4.2 Plant height

3.4.2.1 2016/17

Plant height at physiological maturity was significantly affected by maturity group and plant density as the main effect as well as the interaction effect on MG by PD (Table 3.4).

Plant height was significantly affected by maturity group with MG 4.5 recording the highest plant height (89.67 cm) followed by MG 6 (89.58 cm) which were similar, with both significantly and approximately 23% greater than that of MG 5 (73.17 cm) (Figure 3.1). With plant density, plant height increased from 200 000 (73.11 cm) to 300 000 (76.44 cm) plants ha^{-1} with these two plant densities being similar and significantly lower than that of 400 000 (93.89 cm) and 500 000 (93.11 cm) plants ha^{-1}, which were also similar, with the latter nearly 24% taller that the aforementioned (Figure 3.2).

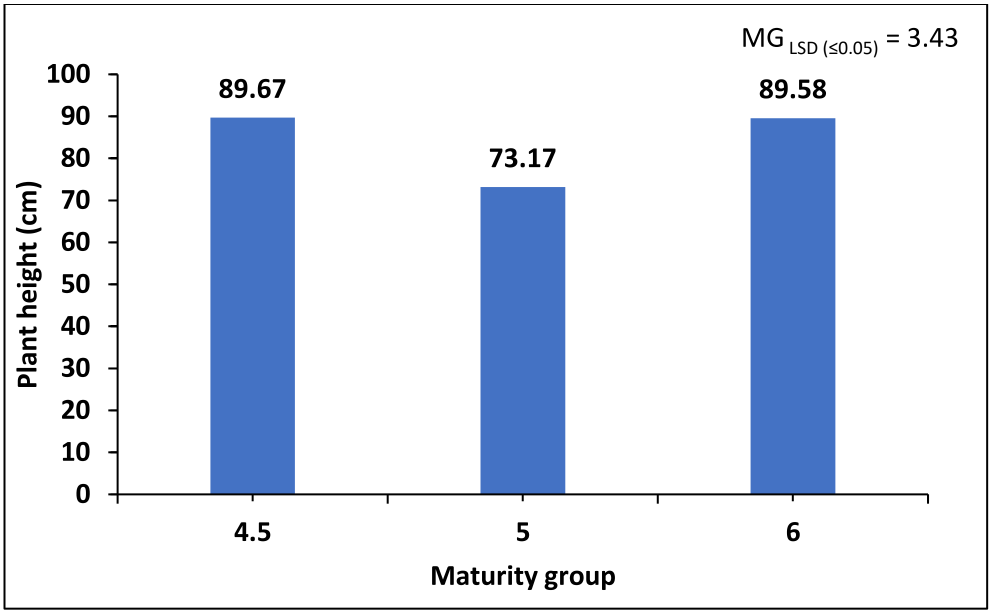

Figure 3.1 Effect of maturity group on plant height.

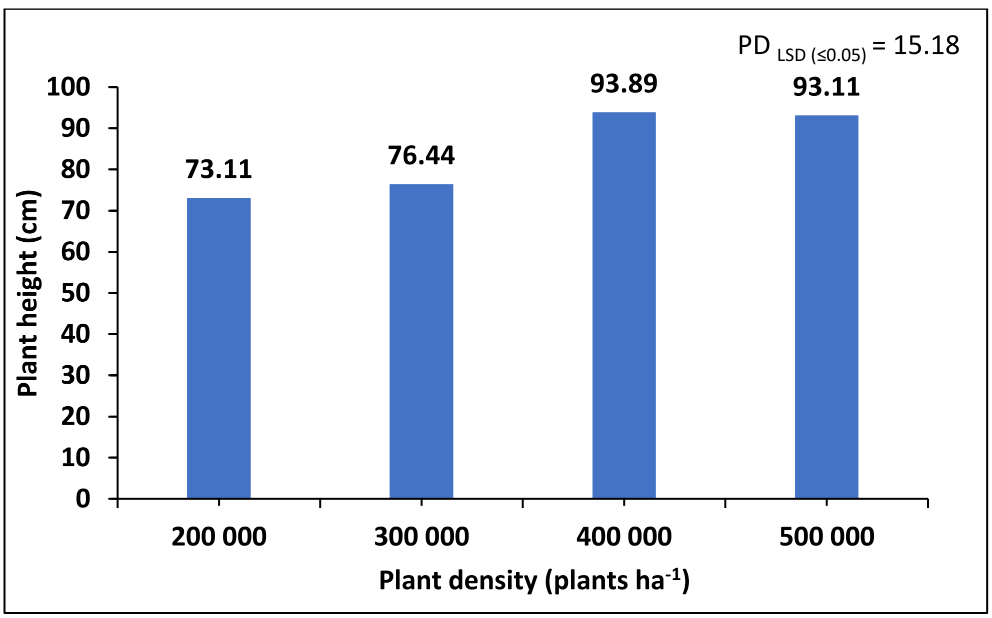

Figure 3.2 Effect of plant density on plant height.

The interaction effect of MG by PD had a significant effect on plant height (Table 3.7). The greatest plant height (100.00 cm) was recorded for MG 6 at 400 000 plants ha^{-1}, followed by MG 4.5 at 400 000 plants ha^{-1} (98.30 cm) and MG 6 at 500 000 plants ha^{-1} (98.30 cm), and lastly MG 4.5 at 500 000 plants ha^{-1} (96.00 cm). The plant height of these four treatment combinations did not differ significantly from each other, but their plants were significantly taller than those of all other treatment combinations. The smallest plant height (60.00 cm) was recorded for MG 5 at 200 000 plants ha^{-1} followed by MG 5 at 300 000 plants ha^{-1} (64.33 cm). In general, plant height increased with increasing plant density. Amongst maturity groups, MG 4.5 recorded the highest plant height as 200 000 (81.00 cm) and 300 000 plants ha^{-1} (83.33 cm) with MG 6 recording the highest plant height at 400 000 (100.00 cm) and 500 000 plants ha^{-1} (98.33 cm). Both MG 5 and MG 6 recorded significantly higher plant heights than those of MG 5 at all plant densities, with no significant difference between MG 5 and MG 6.

Table 3.7 Effect of maturity group and plant density on plant height (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
200 000	81.00	60.00	78.33	73.11
300 000	83.33	64.33	81.67	76.44
400 000	98.33	83.33	100.00	93.89
500 000	96.00	85.00	98.33	93.11
Mean	89.67	73.17	89.58	

MG x PD $_{LSD\ (\leq 0.05)}$ = 7.52

3.4.2.2 2017/18

Plant height at physiological maturity was significantly affected by maturity group and plant density as main effects, as well as the interaction effect of MG by PD (Table 3.4).

Plant height was significantly affected by maturity group with MG 6 recording the highest plant height (85.83 cm), followed by MG 4.5 (83.58 cm), both with a significantly higher plant height than that of MG 5 (72.33 cm) (Figure 3.3). With plant density, 200 000, 300 000 and 400 000 plants ha^{-1} recorded similar plant heights of 79.00 cm, 78.89 cm and 79.44 cm respectively, which were significantly lower than those of 500 000 plants ha^{-1} (85.00 cm) (Figure 3.4).

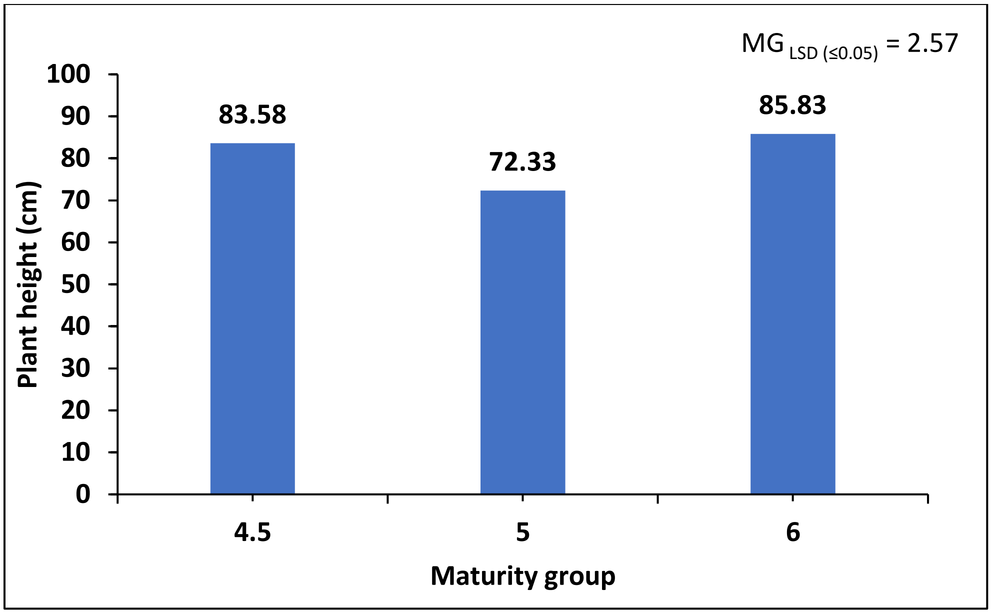

Figure 3.3 Effect of maturity group on plant height.

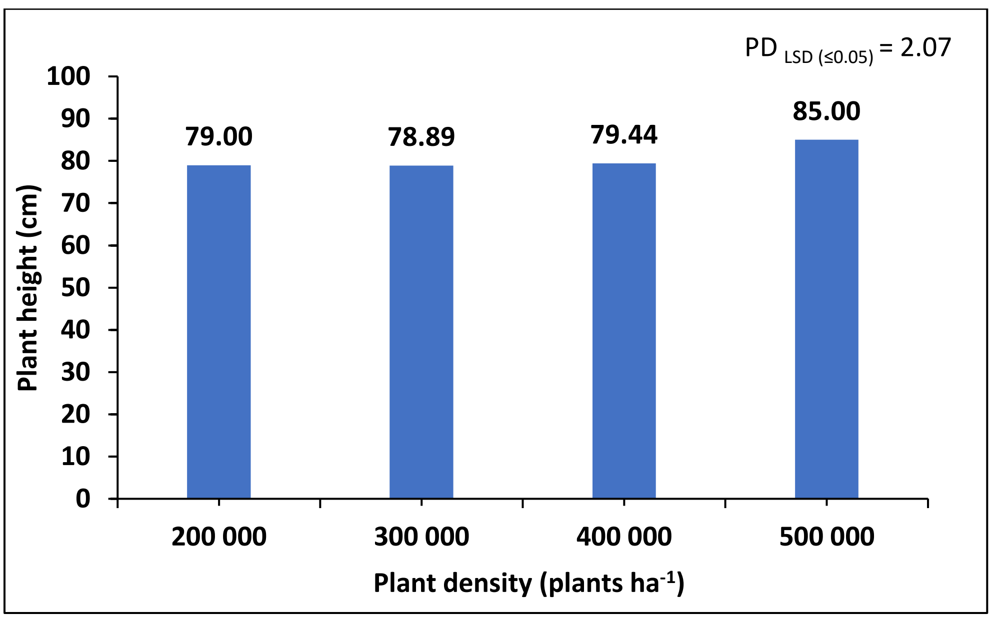

Figure 3.4 Effect of plant density on plant height.

The MG by PD interaction effect significantly affected plant height (Table 3.8). The highest plant height (90.00 cm) was recorded for MG 4.5 and MG 6 at 500 000 plants ha^{-1}, which were taller (3.8%) than the second tallest plants recorder for MG 6 at 300 000 and 400 000 plants ha^{-1} (86.67 cm). The lowest plant height (70.00 cm) was recorded for MG 5 at 300 000 and 400 000 plants ha^{-1}, followed by MG 5 at 200 000 and 500 000 plants ha^{-1} (75.00 cm). In general, the plant height of MG 5 was significantly inferior

(± 15% shorter) than that of MG 4.5 and MG 6, similar to the heights recorded during 2016/17 cropping season. Plants grown at 500 000 plants ha^{-1} were taller than all lower plant densities, and significantly taller for MG 4.5 only.

Table 3.8 Effect of maturity group and plant density on plant height (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
200 000	82.67	74.33	80.00	79.00
300 000	80.00	70.00	86.67	78.89
400 000	81.67	70.00	86.67	79.44
500 000	90.00	75.00	90.00	85.00
Mean	83.58	72.33	85.83	

MG x PD $_{LSD\ (\leq 0.05)}$ = 5.81

For both the 2016/17 and 2017/18 season, MG 4.5 and MG 6 recorded similar plant heights which were significantly taller compared to that of MG 5. Plant height generally increased with increased plant density for both seasons, while more profound during the 2016/17 season.

This study is in agreement with Matsuo *et al*., (2018) who reported that maturity group significantly affected plant height, as well as the interaction effect of MG by PD. Patel and Singh (2008), Yigezu (2014), Mondal *et al*., (2014) and Khubele (2015) also reported that maturity group significantly affected plant height. According to Board (2000), Shamsi and Kobraee (2009), Mellendorf (2011) and Osman (2011) increasing plant density contributed to increased plant height. This result also supports previous findings by De Bruin and Pedersen (2008a) who reported that plant height for 316 000 and 402 700 plants ha^{-1} were 2 to 6 cm higher compared to those of 166 900 and 258 600 plants ha^{-1}. Ahmad *et al*., (2002), Caliskan *et al*., (2004) and Yigezu (2014) also reported that plant density affected plant height significantly, but in contrast to the results of this study, they reported that plant height decreased with increased plant density. Furthermore, in contrast to this study, Cox and Cherney (2011) reported that plant density had no significant effect on plant height.

3.4.3 Pod clearance

3.4.3.1 2016/17

Pod clearance was significantly affected by maturity group as main effect as well as the interaction effect of MG by PD (Table 3.4).

Pod clearance was significantly affected by maturity group. Pod clearance increased from MG 4.5 (11.67 cm) to MG 5 (22.25 cm) as well as to MG 6 (30.0 cm), with 90.7% and 157%, respectively (Figure 3.5).

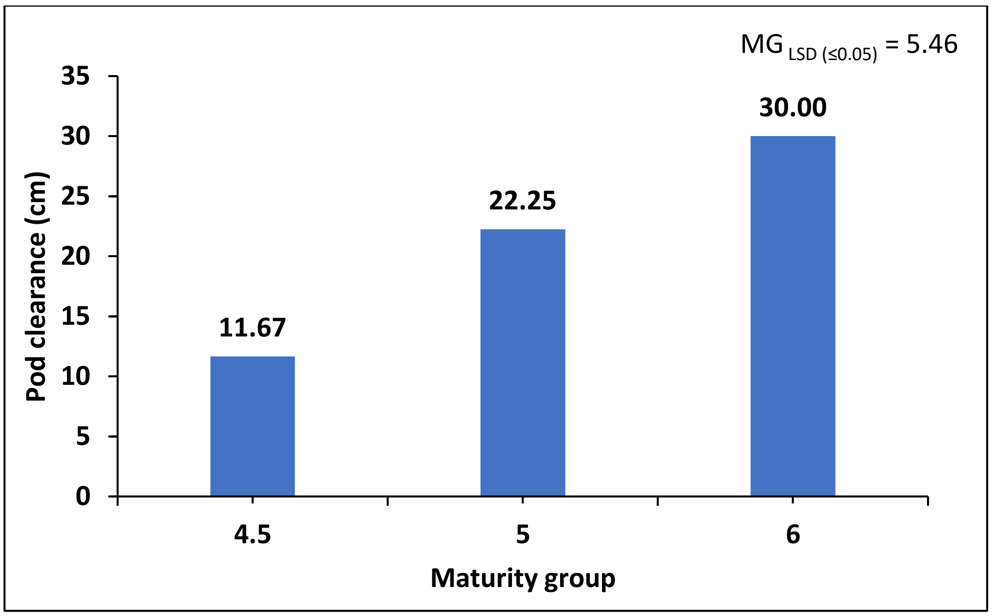

Figure 3.5 Effect of maturity group on pod clearance.

The MG by PD interaction significantly affected pod clearance (Table 3.9). The greatest pod clearance (31.67 cm) was recorded for MG 6 at 500 000 plants ha^{-1}, followed by MG 6 at 400 000 (30.67 cm), 200 000 (29.67 cm) and 300 000 plants ha^{-1} (28 cm). These pod clearances did not differ significantly from each other. The lowest pod clearances (11.33 cm) were recorded for MG 4.5 with all plant densities, with pod clearances varying from 11.33 to 12.33 cm. With the exception of MG 5, there were no significant differences in pod clearance within each maturity group, only between maturity groups at each plant density. MG 6 recorded the greatest pod clearance compared to that of MG 5 and MG 4.5 at all plant densities except for MG 5 at 300 000 plants ha^{-1}. MG 5 recorded the second greatest pod clearance, significantly higher than that of MG 4.5 at all plant densities.

Table 3.9 Effect of maturity group and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	Maturity group			
	4.5	5	6	Mean
200 000	11.33	18.33	29.67	19.78
300 000	11.67	23.33	28.00	21.00
400 000	11.33	24.00	30.67	22.00
500 000	12.33	23.33	31.67	22.44
Mean	11.67	22.25	30.00	

MG x PD $_{LSD\ (\leq 0.05)}$ = 5.08

3.4.3.2 2017/18

Pod clearance was significantly affected by the main effects of maturity group and plant density as well as the interaction effect of MG by PD (Table 3.4). Similar to the 2016/17 season, pod clearance was affected more by maturity group than plant density.

Pod clearance was significantly affected by maturity group with pod clearance increasing significantly from MG 4.5 (8.83 cm) to MG 5 (19.75 cm) as well as to MG 6 (29.83 cm), with 125% and 239% (Figure 3.6). For plant density, the only significant difference was recorded at 400 000 plants ha^{-1} (20.22 cm) which had a higher pod clearance than that of 500 000 plants ha^{-1} (19.11 cm) (Figure 3.7).

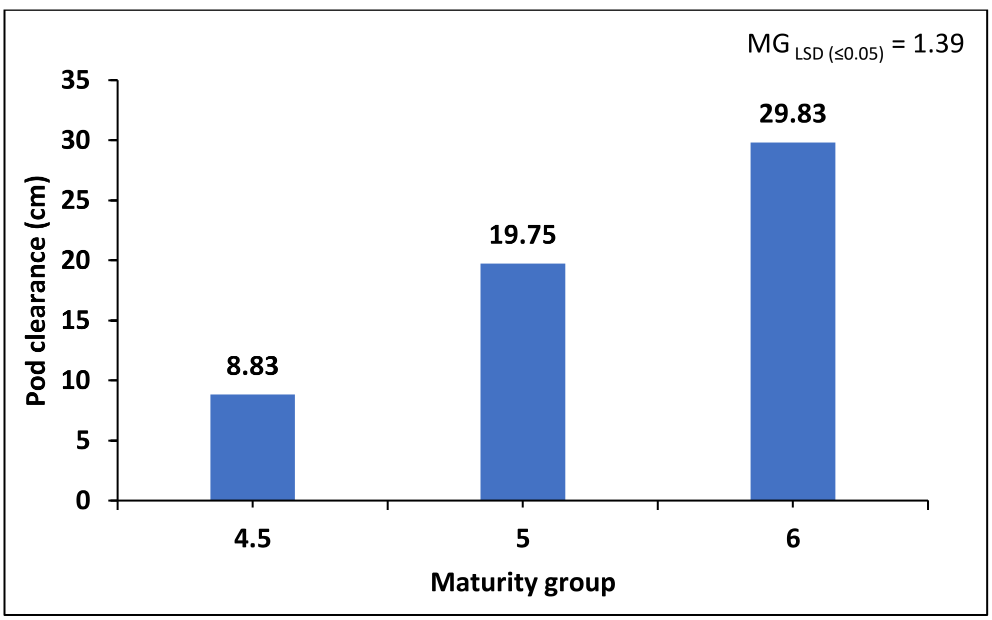

Figure 3.6 Effect of maturity group on pod clearance.

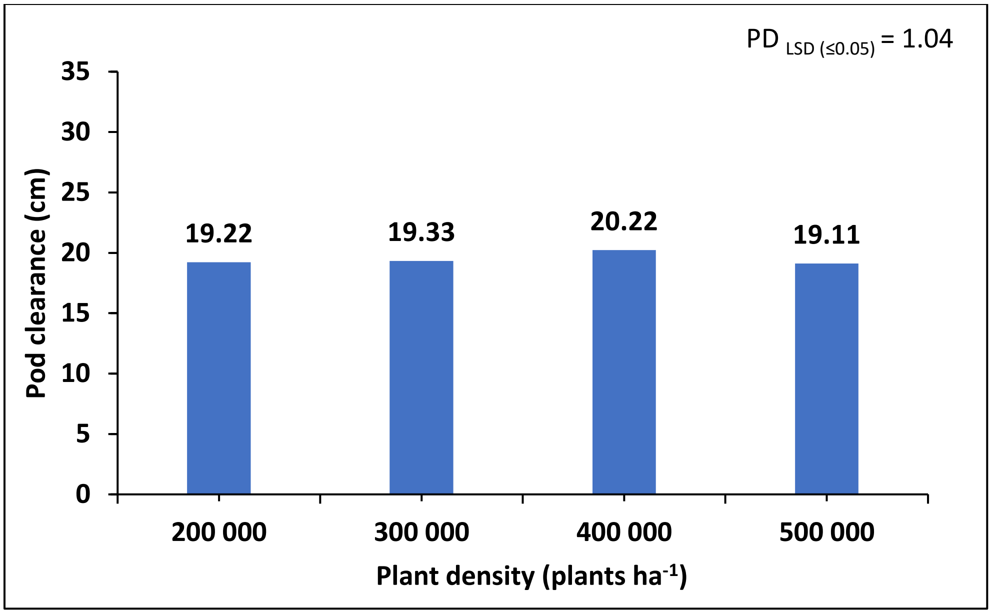

Figure 3.7 Effect of plant density on pod clearance.

Pod clearance was significantly affected by the interaction effect of MG by PD (Table 3.10). The greatest pod clearance (30.33 cm) was recorded for MG 6 at 400 000 plants ha^{-1}, followed by MG 6 at 300 000 and 200 000 plants ha^{-1} (30.00 cm) as well as MG 5 and 6 at 500 000 plants ha^{-1} (29.00 cm). The lowest pod clearance (8.33 cm) was recorded for MG 4.5 at 200 000 and 500 000 plants ha^{-1}, followed by 300 000 plants ha^{-1} (9.00 cm) and 400 000 plants ha^{-1} (9.67 cm). There were highly significant differences between maturity groups, with no significant differences between plant densities within all maturity group treatments, except for MG 5 at 500 000 plants ha^{-1}. The latter recorded a significantly higher pod clearance (29.00 cm) compared to the other plant densities within MG 5. MG 6 recorded the highest pod clearance compared to that of MG 5 and MG 4.5 at all plant densities. MG 5 recorded the second greatest pod clearance, significantly greater than that of MG 4.5 at all plant densities.

Table 3.10 Effect of maturity group and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
200 000	8.33	19.33	30.00	19.22
300 000	9.00	19.00	30.00	19.33
400 000	9.67	20.67	30.33	20.22
500 000	8.33	29.00	29.00	19.11
Mean	8.83	19.75	29.83	

MG x PD $_{LSD\ (\leq 0.05)}$ = 3.27

In this study maturity group had the greatest significant effect on pod clearance, while the effect of plant density was negligible. According to Matsuo *et al.*, (2018) maturity group affected pod clearance significantly which is in agreement with this study, while pod clearance increased with increased plant densities. In many studies done and literature reviewed, the study conducted by Matsuo *et al.,* (2018) was unfortunately the only to measure pod clearance. Thus, only this study's pod clearance results could be used for comparative purposes. Pod clearance is important because it plays an important role in seed recovery during mechanical harvesting.

3.4.4 Number of pods per plant

3.4.4.1 2016/17

The number of pods per plant was significantly affected by the plant density main effect as well as the interaction effects of MG by PD (Table 3.4).

The number of pods per plant was significantly affected by plant density, with the number of pods per plant decreasing with increasing plant density (Figure 3.8). Number of pods per plant decreased significantly only from 200 000 plants ha^{-1} (47.53) to 300 000 (35.03), whereafter, only decreasing to 400 000 (32.47) and 500 000 plants ha^{-1} (31.37), with 26%, 31% and 34% respectively. Between 300 000, 400 000 and 500 000 plants ha^{-1} there were no significant differences.

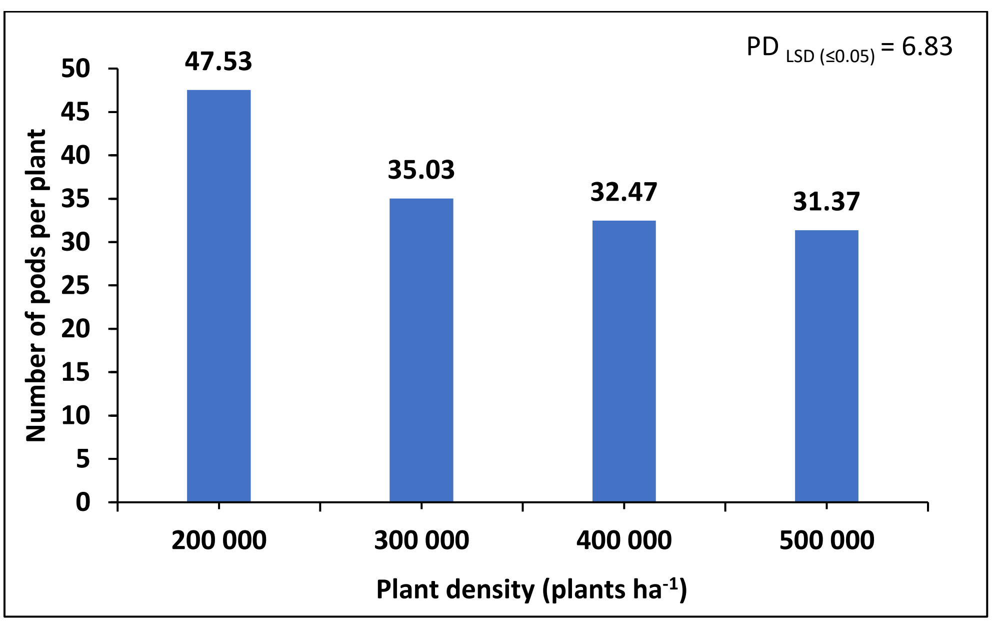

Figure 3.8 Effect of plant density on the number of pods per plant.

The MG by PD interaction significantly affected the number of pods per plant (Table 3.11). The greatest number of pods per plant (57.47) was recorded for MG 6 at 200 000 plants ha^{-1} followed by MG 5 at 200 000 plants ha^{-1} (48.20). The lowest number of pods per plant (26.93) was recorded for MG 5 at 500 000 plants ha^{-1}, followed by MG 5 at 300 000 plants ha^{-1} (29.77) and MG 6 at 400 000 plants ha^{-1} (31.33). With the exception of MG 4.5 at both 200 000 and 300 000 plants ha^{-1}, and MG 5 at 200 000 plants ha^{-1}, all other treatment combinations yielded significantly lower pod counts than that of MG 6 at 200 000 plants ha^{-1}, while MG 5 at 200 000 plants ha^{-1} (48.20) recorded a significantly greater pod number than MG 5 at 500 000 plants ha^{-1} only. These were the only significant differences. There was no trend regarding what affected the number of pods per plant the most in this set of data.

Table 3.11 Effect of maturity group and plant density on the number of pods per plant

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
200 000	36.93	48.20	57.47	47.53
300 000	39.10	29.77	36.23	35.03
400 000	31.63	34.43	31.33	32.47
500 000	32.77	26.93	34.40	31.37
Mean	35.11	34.83	39.86	

MG x PD $_{LSD\ (\leq 0.05)}$ = 20.71

3.4.4.2 2017/18

The number of pods per plant was significantly affected by the main effect of plant density as well as the interaction effect of MG by PD (Table 3.4).

Plant density significantly affected number of pods per plant with this number decreasing from 200 000 plants ha^{-1} (37.20) to 300 000 plants ha^{-1} (31.40) as well as to 400 000 plants ha^{-1} (22.40) and 500 000 plants ha^{-1} (28.10), by 15.6%, 39.8% and 24.5% respectively (Figure 3.9). A significantly greater number of pods per plant was recorded for 200 000 plants ha^{-1} compared to than that by 400 000 and 500 000 plants ha^{-1}.

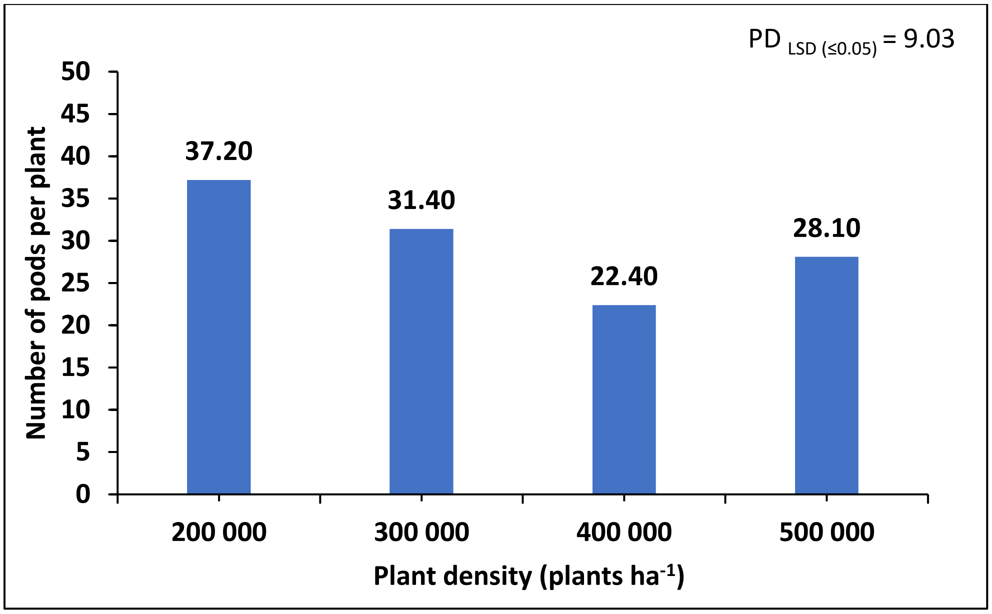

Figure 3.9 Effect of plant density on the number of pods per plant.

The MG by PD significantly affected the number of pods per plant (Table 3.12). The greatest number of pods per plant (40.80) was recorded for MG 6 at 200 000 plants ha^{-1}, followed by MG 5 at 200 000 plants ha^{-1} (40.47) and MG 6 at 300 000 (33.63). The lowest number of pods per plant (17.27) was recorded for MG 4.5 at 400 000 plants ha^{-1}, followed by MG 5 at 400 000 plants ha^{-1} (22.63) and MG 6 at 500 000 plants ha^{-1} (25.70). In general, number of pods per plant decreased with each increment increase in plant density. Amongst maturity groups at each plant density, no significant differences in number of pods per plant were evident.

Table 3.12 Effect of maturity group and plant density on the number of pods per plant

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
200 000	30.37	40.47	40.80	37.20
300 000	27.73	32.87	33.63	31.40
400 000	17.27	22.63	27.33	22.40
500 000	29.77	28.73	25.70	28.10
Mean	26.30	31.20	31.90	

MG x PD $_{LSD\ (\leq 0.05)}$ = 22.15

The results of this study are in agreement with those of Pilbeam *et al*., (1991), Mellendorf (2011) and Yigezu (2014) who reported a decrease in the number of pods per plant as a result of increased plant density. According to these researchers, the reduction in pod number per plant was due to soya beans being subjected to more interplant competition which suppressed the ability to produce more pods per plant. In contrast, Osman (2011), Yigezu (2014) and Khubele (2015) reported that different maturity groups resulted in significant differences in the number of pods per plant.

The decrease in the number of pods per plant with corresponding increase in plant density might be attributed to increased competition between plants for water, nutrients, and sunlight (Yada, 2011). This might also be due to the development and vigorous leaf growth of low plant densities and improved photosynthetic efficiency, resulting in a larger number of pods per plant. On the other hand, soya beans have a great compensation ability to produce more pods per plant where plant density is low or insufficient which is in agreement with Lopez-Bellido *et al*., (2005) and Abdel (2008) who observed that soya beans, common bean and faba bean display considerable plasticity in response to varying plant densities, especially to number of pods per plant. Although maturity group did not affect number of pods per plant significantly in both seasons, Zafar *et al*., (2003) reported that soya beans have the presence of a genetic regulatory system through which it is possible for the plant to direct and concentrate available nutrients to permit development of more number of pods per plant and seeds per pod. These features are a response to different factors affecting growth and development such as differences in plant density.

3.4.5 Number of seeds per pod

3.4.5.1 2016/17 and 2017/18

Analysis of variance indicated that the interaction effect of maturity group and plant density resulted in no significant differences in number of seeds per pod for both the 2016/17 and 2017/18 season (Data not shown). Number of seeds per pod was also not significantly affected by either of the main effects for both seasons. This concurs with the findings of Osman (2011) who also found that maturity group had no significant effect on the number of seeds per pod. In contrast to this study's results, Yigezu (2014), Khubele (2015) and Matsuo (2018) reported that maturity group and plant density did affect the number of seeds per pod significantly, with differences between maturity groups and number of seeds per pod decreasing with increased plant density.

3.4.6 Hundred-seed weight

3.4.6.1 2016/17

Hundred-seed weight was significantly affected by maturity group as main effect (Table 3.4).

Maturity group significantly affected hundred-seed weight with MG 4.5 recording the greatest hundred-seed weight with 14.58 g, significantly greater than both MG 5 and MG 6 with a hundred-seed weight of 11.89 g and 10.06 g, respectively (Figure 3.10). Between MG 5 and MG 6 there was no significant difference in hundred-seed weight.

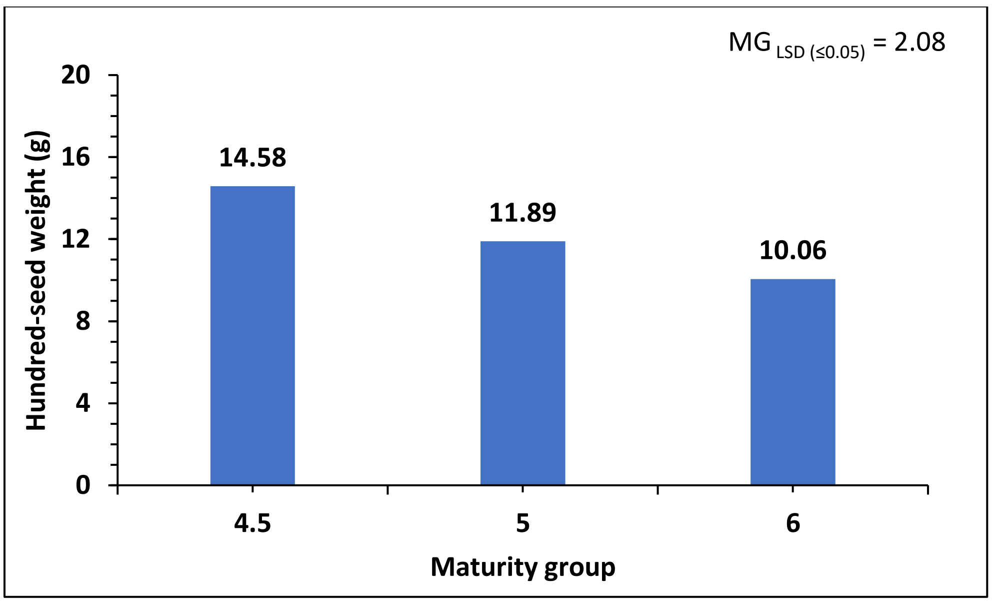

Figure 3.10 Effect of maturity group on the hundred-seed weight.

3.4.6.2 2017/18

Hundred-seed weight was significantly affected by maturity group as main effect, similar to the 2016/17 season (Table 3.4).

Maturity group significantly affected hundred-seed weight with MG 4.5 recording the greatest hundred-seed weight with 11.54 g, significantly greater than both MG 5 and MG 6 with a hundred-seed weight of 8.32 g and 7.88 g, respectively (Figure 3.11). Between MG 5 and MG 6 there was no significant difference in hundred-seed weight.

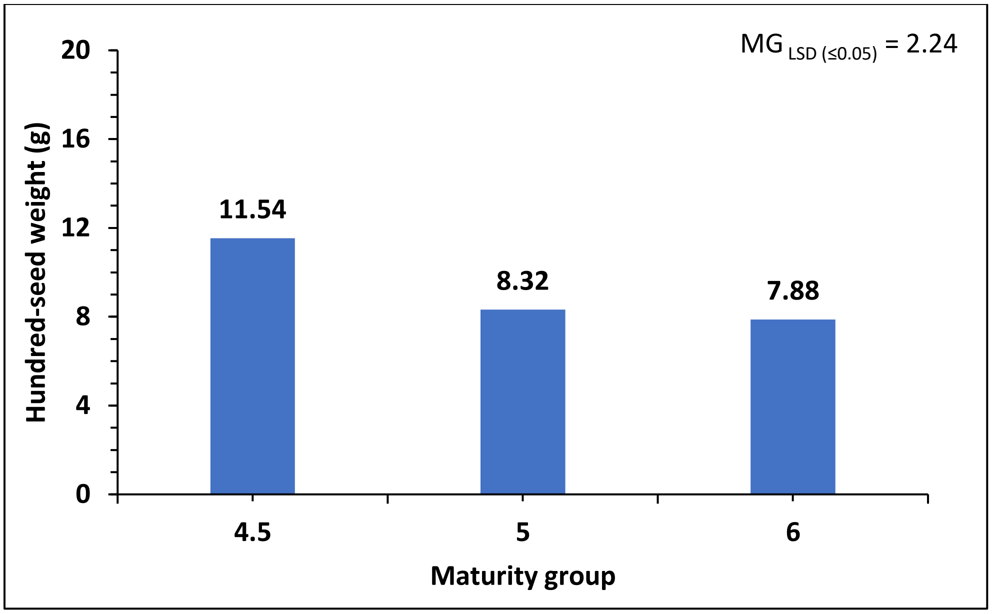

Figure 3.11 Effect of maturity group on the hundred-seed weight.

Hundred-seed weight was significantly affected by maturity group as main effect for both the 2016/17 and 2017/18 season. During both seasons, MG 4.5 significantly recorded the greatest hundred-seed weight, followed by MG 5 and MG 6 with no significant difference between the latter two maturity groups.

This study is in agreement with Yigezu (2014) and Matsuo (2018) who reported that the main effect of maturity group had a highly significant effect on hundred-seed weight. Board (2000) and Mellendorf (2011) reported that hundred-seed weight was not affected by plant density. In contrast to this study's results Osman (2011) reported that maturity group did not affect hundred-seed weight significantly, while Yigezu (2014) and Matsuo (2018) reported that plant density affected hundred-seed weight with hundred-seed weight decreasing with increased plant density.

These different and/or contrasting findings have to be interpreted in relation to varying genotypes, environmental conditions as well as agronomic practices. Furthermore, it has to be noted that soya bean genotype is sensitive and therefore specific to different agro-ecologies.

3.4.7 Yield (t ha^{-1})

3.4.7.1 2016/17

Grain yield was significantly affected by plant density as main effect as well as the interaction effect of MG by PD (Table 3.4).

Plant density significantly affected grain yield with 200 000 and 300 000 plants ha^{-1} recording the lowest grain yields with 2.71 t ha^{-1} and 2.55 t ha^{-1}, respectively and were not significantly different but were indeed significantly lower than that of 500 000 plants ha^{-1}, while that of 200 000 plants ha^{-1} was also significantly lower than that of 400 000 plants ha^{-1} (Figure 3.12).

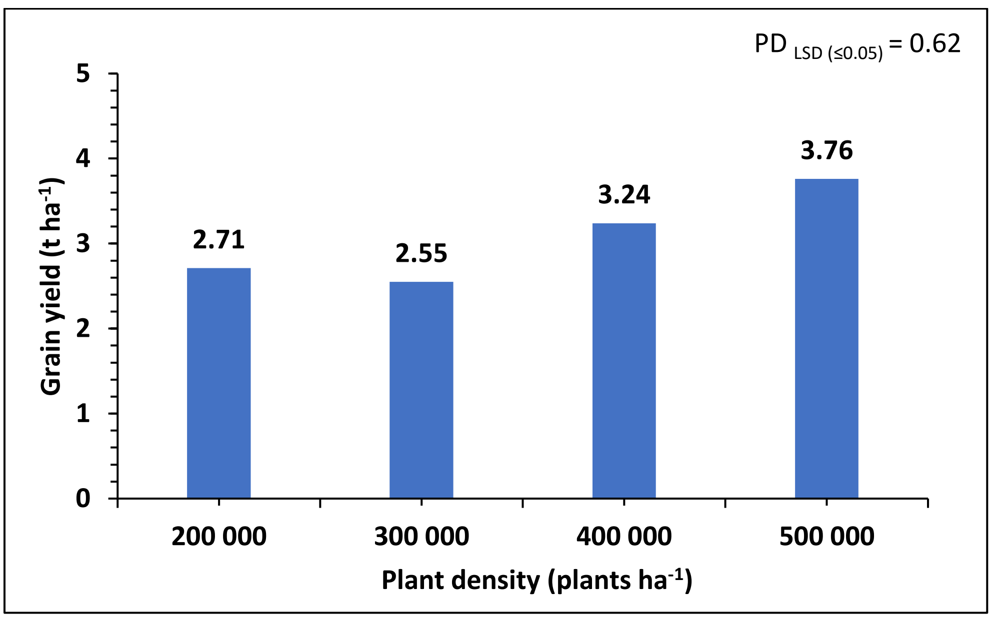

Figure 3.12 Effect of plant density on grain yield (t ha^{-1}).

The MG by PD interaction significantly affected grain yield (Table 3.13). MG 4.5 at 500 000 plants ha^{-1} recorded the greatest grain yield (4.04 t ha^{-1}) followed by MG 4.5 at 400 000 plants ha^{-1} (3.67 t ha^{-1}), MG 5 at 500 000 plants ha^{-1} (3.61 t ha^{-1}) as well as MG 6 at 500 000 plants ha^{-1} (3.61 t ha^{-1}). These treatment combinations did not differ significantly in yield. The lowest grain yield (2.02 t ha^{-1}) was recorded for MG 5 at 300 000 plants ha^{-1}, followed by MG 6 at 200 000 (2.45 t ha^{-1}) and MG 4.5 at 200 000 plants ha^{-1} (2.69 t ha^{-1}). In general, the plant density of 500 000 plants ha^{-1} resulted in the greatest grain yield for all maturity groups and declined progressively with a reduction in plant density. MG 4.5 generally recorded the greatest grain yield at all plant densities compared to that of MG 5 and MG 6, except at 200 000 plants ha^{-1}, where MG 4.5 recorded the lowest grain yield.

Table 3.13 The effect of maturity group and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Maturity group			
	4.5	5	6	Mean
200 000	2.69	2.72	2.71	2.71
300 000	3.19	2.02	2.45	2.55
400 000	3.60	2.98	3.08	3.24
500 000	4.04	3.61	3.61	3.76
Mean	3.40	2.83	2.96	

MG x PD $_{LSD\ (\leq 0.05)}$ = 0.99

3.4.7.2 2017/18

Grain yield was significantly affected by maturity group as main effect as well as the interaction effect of MG by PD (Table 3.4).

Maturity group significantly affected grain yield with, the greatest grain yield (2.19 t ha^{-1}) recorded with MG 4.5. Thereafter, grain yield decreased for MG 5 (1.82 t ha^{-1}) and MG 6 (1.59 t ha^{-1}) with 17% and 27.5%, respectively. Both MG 5 and MG 6 recorded a significantly lower grain yield compared to that of MG 4.5, with no significant difference between the above mentioned.

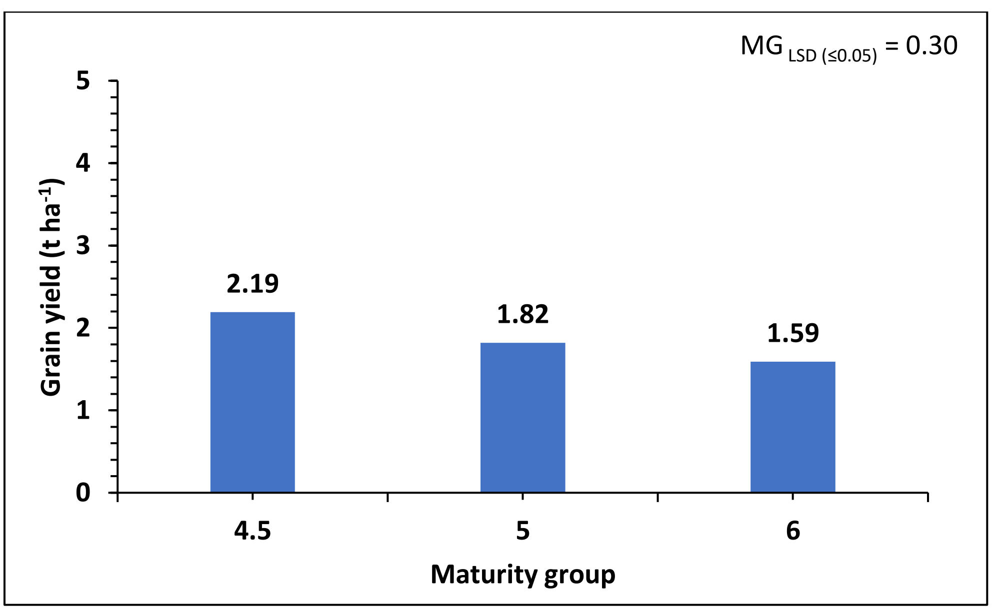

Figure 3.13 Effect of maturity group on grain yield.

The MG by PD interaction significantly affected grain yield (Table 3.14). MG 4.5 at 500 000 plants ha^{-1} recorded the greatest grain yield (2.58 t ha^{-1}) followed by MG 4.5 at 200 000 plants ha^{-1} (2.30 t ha^{-1}), and 300 000 plants ha^{-1} (1.97 t ha^{-1}). The lowest grain yield was recorded within MG 6 at 400 000, 300 000 and 200 000 plants ha^{-1} with 1.45, 1.49 and 1.51 t ha^{-1}, respectively. MG 4.5 yielded higher than MG 5 and 6 over all plant densities. Furthermore, the grain yields obtained with MG 4.5 were significantly greater than those obtained with MG 5 at 500 000 plants ha^{-1} as well as MG 6 at both 200 000 and 500 000 plants ha^{-1}. Within each maturity group, plant density only had a significant effect on grain yield within MG 4.5 with 500 000 plants ha^{-1} (2.58 t ha^{-1}) recording a significantly greater grain yield than both 300 000 (1.97 t ha^{-1}) and 400 000 plants ha^{-1} (1.93 t ha^{-1}).

Table 3.14 The effect of maturity group and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
200 000	2.30	1.95	1.51	1.92
300 000	1.97	1.86	1.49	1.77
400 000	1.93	1.71	1.45	1.69
500 000	2.58	1.77	1.92	2.09
Mean	2.19	1.82	1.59	

MG x PD $_{LSD\ (\leq 0.05)}$ = 0.53

Grain yield was significantly affected by plant density during the 2016/17 season. Maturity group also had an effect on grain yield, although not to a significant extend, while MG 4.5 still recorded over 400 kg ha^{-1} more than both MG 5 and MG 6. During the 2017/18 season maturity group significantly affected grain yield with MG 4.5 yet again recording the greatest grain yield, more than 300 and 600 kg ha^{-1} compared to MG 5 and MG 6, respectively. Plant density had a lesser effect on grain yield during this season. The reason for this might possibly be attributed to lower than average rainfall during the months of March and April for the 2016/17 season, and due to planting date during the 2017/18 season. This statement is explained below.

In general, early planting dates favour longer maturity groups such as MG 5 and MG 6 in terms of grain yield (Boquet, 1998). By contrast, this was not reflected during the 2016/17 season. Planting was 26 October, which is considered an early/normal planting date in the North Eastern Free State and the longer maturity groups did not produce higher yields as generally expected. This was due to low rainfall during March and April (Table 3.1) where MG 5 and MG 6 were in the seed-fill (R5-R6) stage, while MG 4.5 already completed seed-filling. This resulted in lower grain yields for MG 5 and 6, while MG 4.5 could produce an optimum grain yield. This was also clearly evident in the hundred-seed weight of the 2016/17 season. The 2017/18 season was characterized by lower than average rainfall early in the season, resulting in later planting dates. The planting date for this season was 29 November, considered to be a late planting date, resulting in a shorter growing season, which effects longer maturity groups negatively. Hence MG 4.5 once more produced higher yields than MG 5 and 6.

Results concur with Boquet (1998), who reported that maturity group selection and planting date were the most important factors affecting soya bean yield. Frederick *et al*., (2001) also reported that drought stress during seed-filling reduced grain yield, resulting in the lower than expected grain yields during the 2016/17 season.

The results of this study are in agreement with Osman (2011), Hu (2013), Mondal *et al*., (2014), Yigezu (2014) and Matsuo *et al*., (2018) who all reported that maturity group had a significant effect on grain yield. Egli *et al*., (1988), Ball *et al*., (2000) and Yigezu (2014) reported that increasing plant densities resulted in significantly increasing grain yield. According to Egli *et al*., (1988) higher plant densities reached canopy closure earlier, ensuring maximum light interception earlier in the season. This in turn resulted in increased grain yield. According to Matsuo *et al*., (2018) grain yield increased significantly from 71 000 plants ha^{-1} to 143 000 plant ha^{-1}, whereafter decreasing to 250 000 plants ha^{-1}. Furthermore, Meckel *et al*., (1984) also reported that water stress during the later phases of the reproductive stages decreased the duration of the seed-filling stage, resulting in lower grain yields.

3.5 Summary and Conclusion

Maturity group, plant density and the interaction effect influenced all parameters measured, significantly, except for the number of days to 50% flower initiation, and physiological maturity where maturity group had the only influence. The number of seeds per pod was not influenced by both maturity group and plant density, or by the interaction effect.

Maturity group was the treatment factor that significantly affected phenological development i.e. number of days to 50% flower initiation (R1), flower initiation to incipient seed-filling (R1-R5), incipient seed-filling to physiological maturity (R5-R8), and the total growth period. MG 4.5 reached R1 and R8 in the shortest number of days for both cropping seasons, followed by MG 5 and MG 6. This is due to the varietal characteristics of each maturity group, which is controlled by the specific maturity group's genetics and each particular response to photo period. Generally, plant height and pod clearance increased with increasing plant densities for both the 2016/17 and 2017/18 season. Plant height for MG 4.5 and 6 was significantly higher than MG 5, while pod clearance increased significantly from MG 4.5 to MG 5 and MG 6. Plant height was equally influenced by maturity group and plant density, while maturity group influenced pod clearance more than plant density. These results prove that soya beans show great plasticity regarding the adaptability to change or to regulate growth in response to various agronomic factors.

Number of pods per plant generally decreased with increasing plant densities, while maturity group had no significant effect. MG 6 produced the highest number of pods per plant for both seasons, while the greatest number of pods per plant was recorded at 200 000 plants ha^{-1} within all three maturity groups for both seasons. Plant density had no influence on the hundred-seed weight, while maturity group had a significant influence. MG 4.5 produced a significantly higher hundred-seed weight followed by MG 5 and, MG 6 with the lowest weights.

Grain yield was significantly influenced by both maturity group and plant density. MG 4.5 had significantly higher yields than MG 5 and MG 6 for the 2017/18 season only. The 2016/17 season yielded over 400 kg (14%) more than MG 5 and MG 6, but this was not viewed as significant. For both seasons there were no significant differences between MG 5 and MG 6. Grain yield increased with increasing plant density during the 2016/17 season only, with 500 000 plants ha^{-1} producing the highest soya bean grain yield for both seasons. Grain yield was significantly affected by both maturity group and plant density, while planting date and rainfall also affected the response of grain yield to maturity group as already discussed above (3.4.7.2 2017/18 results and discussion).

In conclusion, it is evident that maturity group had the greatest effect on physiological development, pod clearance and hundred-seed weight, while plant density had the greatest effect on number of pods per plant. Both maturity group and plant density affected plant height and grain yield equally. These factors alone, or in combination, cannot be singled out and have to be factored into different planting dates.

Chapter 4

The influence of maturity group, plant density and row width on the growth, yield components and yield of soya beans (*Glycine max* L.) in the North Eastern Free State between Vrede and Cornelia

4.1 Introduction

The effect of maturity group and plant density as well as uncontrollable and other controllable factors that influence soya bean production was discussed in the previous chapter (see chapter 3.1). It should be noted that row width is another controllable agronomic input that greatly affects soya bean production.

Row width is one subject that has prompted many studies, with mixed findings. The overall common understanding is that narrow rows tend to produce higher yields compared to wider rows (Vonk, 2013). It is believed that the yield advantage from narrow rows is due to better water use and light interception (Caliskan *et al*., 2007), as well as a more equidistant plant arrangement, reducing inter row competition between plants for water, nutrients and sunlight (Yada, 2011). The rapid canopy closure also enhances weed management, increases plant establishment and decreases evaporation (Hoeft *et al*., 2000). According to Bullock *et al*., (1998) soya bean yield increases as row width decreases. Narrow row widths of 0.38 m out yielded wider row widths of 0.76 m and 1.14 m by 8% and 20% respectively, while 0.76 m out yielded 1.14 m by 12%. Narrow row widths out yielded wider row widths by 284 kg ha^{-1} (6.2%) (De Bruin and Pedersen, 2008b). Reports that row width had no effect on grain yield were also found (Pedersen and Lauer, 2003). Costa *et al*., (1980) reported a substantial increased grain yield for narrow rows with early maturity groups. According to James *et al*., (1996) higher yields were also obtained for early maturing maturity groups with narrow row widths and high plant densities, compared to wider rows with low plant densities.

The effect of row width on soya bean production also varies between different conditions. According to Alessi and Power (1982), in water stress conditions narrow row width can have a negative effect of yield due to increased water use early in the season. This results in less water availability during critical development stages. Planting date also affects the response of soya beans to row width, with Boquet

(1990) reporting that narrow row widths decreased yield loss due to late planting by as much as 16% compared to wider row widths.

Considering the studies that was conducted over a wide range of conditions, and cognisant of the fact that many factors influence selection of maturity group as well as plant density and row width, it is critical to choose the correct combination of each for a specific environment. The objective was to evaluate soya bean response to different maturity groups at different plant densities and row widths in the North Eastern Free State.

4.2 Materials and Methods

4.2.1 Experimental site

Two field experiments were conducted during the 2016/17 and 2017/18 cropping seasons on a farmer's field located in the North Eastern Free State between Vrede and Cornelia. Geographically, the experimental site is situated at 1 610 m above sea level on latitude -27.251534 and longitude 29.028222. Rainfall data measured with a rain gauge on the experimental sites during the two growing seasons are summarized in Table 4.1. The chemical and physical soil properties are summarized in Table 4.2.

Table 4.1 Rainfall (mm) for the 2016/17 and 2017/18 cropping seasons at the experimental sites between Vrede and Cornelia

	Rainfall (mm)									
Season	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
2016/17	12	76	111	89	119	165	4	1	12	**589**
2017/18	5	70	77	176	98	83	143	7	24	**684**

Table 4.2 Chemical and physical soil properties of the experimental sites between Vrede and Cornelia

Physical properties	**Cropping season**	
	2016/17	**2017/18**
Clay (%)	18	20
Density ($g.cm^{-3}$)	1.03	1.03
Chemical properties		
pH (KCl)	5.5	5.1
Nutrients (mg kg^{-1})		
P (Bray 1)	15.9	15.9
K (NH_4OAc)	125.5	188.1
Ca (NH_4OAc)	721	541
Mg (NH_4OAc)	114.3	99.8
Na (NH_4OAc)	2.8	2.1
S (NH_4OAc)	3.93	24.68
Exchangeable acids	0	0
Acid saturation (%)	0	0
Ca/Mg	3.85	3.31
(Ca+Mg)/K	14.14	7.32
CEC (cmolc kg^{-1})	4.87	4.01

* Soil sample taken at a depth of 0-20 cm

4.2.2 Experimental Design and Treatments

The experimental design was a factorial combination laid out in a split-split plot design with four replications. Treatments included three cultivars (maturity groups), four plant densities and two row widths. The main plot factor was maturity group (MG), with plant density (PD) as the sub-plot factor, and row width (RW) as the sub-sub plot factor. The three cultivars, representative of three maturity groups, included SSS 4945 tuc (MG 4.5), SSS 5449 tuc (MG 5) and SSS 6560 tuc (MG 6). MG 4.5 is classified as a short, MG 5 as a medium and MG 6 as a medium-long maturity group. Other cultivar characteristics are summarized in Table 4.3. The four planting densities represented a plant stand of 100 000, 200 000, 270 000 and 400 000 plants ha^{-1} and the two row widths were 0.38 m and 0.76 m.

Each plot consisted of 16 sub-plots and 32 sub-sub plots. Each sub-sub plot was 5 m long with 1 m paths between plots, consisting of three planting rows for the 0.76 m row width and six planting rows for the 0.38 m row widths. The planting rows were spaced 0.38 m (with 6 plant rows) or 0.76 m (with 3 plant rows) apart, making one sub-plot 4.56 m and one sub-sub plot 2.28 m wide. In total there were 3 main plots with 48 sub-plots and 96 sub-sub plots. Each main plot measured 98 m x 4.56 m, each sub-plot 5 m x 4.56 m and each sub-sub plot 5 x 2.28 m. Finally, the total area designated for the experiment measured 1340.64 m^2 (98 m x 13.68 m).

Table 4.3 Cultivar characteristics representing the three (3) maturity groups (MG)

Characteristic	Cultivar		
	SSS 4945 tuc	**SSS 5449 tuc**	**SSS 6560 tuc**
Maturity Group	4.5	5.2	6
Growth Type	Semi-indeterminate	Indeterminate	Indeterminate
Growth Period	Short	Medium	Medium to long
Days to flowering	59	63	70
Days to harvest (moderate – cooler areas)	133 – 144	139 - 157	155 - 171
Plant Height (cm)	65	90	90
Pod clearance (1=high, 9=low)	5	2	2
Standability	Excellent	Good	Good
Shattering resistance	Resistant	Good	Good
Seed Density (Plants/ha^{-1})			
Dryland- Cooler	320 000 - 360 000	300 000 - 340 000	280 000 - 300 000
Dryland- Warmer	380 000	340 000	320 000
Row width/ Thousand seeds ('000)	76 cm 52 cm 38 cm 320 340 360	76 cm 52 cm 38 cm 300 320 340	91 cm 76 cm 52 cm 38 cm 280 280 300 300

4.2.3 Agronomic practices and management of the experimental site

The experiments were conducted under dry land conditions over two cropping seasons (2016/17 and 2017/18) at two different locations on the farm. The preceding crop for both seasons' experimental sites was maize (*Zea mays* L.) on a no-till system. Planting dates were 28 October 2016 for the 2016/17 cropping season, and 7 November 2017 for the 2017/18 cropping season. The planting process was done by a 36-row planter suited for planting soya beans at variable/different planting densities obtained by adjusting planter gears. The planter units were spaced 0.38 m apart. Rows of 0.76 m were obtained by manually removing every second row in the 0.76 m sub-sub-plots. Each maturity group consisted of twelve (12) rows for the 0.38 m row width and six (6) for the 0.76 m row width. Only the middle two and four rows were used to collect data for the 0.76 and 0.38 m rows, respectively. Desired planting densities were obtained by adjusting the planter's gears. The experimental site was fertilized according to best agronomic practices. Fertilizer was broadcasted before planting with a compound fertilizer 1:1:2(20) at 200 kg ha^{-1}. Seeds were inoculated with a *Bradyrhizobium japonicum* inoculant before planting. Weeds were controlled with Roundup PowerMax at a rate of 1.5 L ha^{-1} (540 g a.i. L^{-1}) six (6) weeks after planting.

At harvest, each sub-sub plot was manually harvested, each plant was pulled by hand and transported from the field in poly propylene bags. Plants were threshed mechanically, moisture content determined, and yields adjusted to a 12.5% moisture content.

4.3 Data Collection and Measurements

4.3.1 Phenological development and Growth parameters

a. Phenological development: Number of days from plant to 50% flower initiation (Plant-R1), flower initiation to beginning seed-filling (R1-R5), beginning of seed-filling to physiological maturity (R5-R8) and total growth period (Plant-R8).

b. Days to 50% flower initiation: Days to flower initiation (R1 – when 50% of all plants have an open flower at one of the two uppermost nodes on the main stem with a fully developed leaf) were recorded as the number of days from plant up until the R1 stage for each sub-sub plot.

c. Reproductive growth stage: The stage of reproductive growth was recorded each week from flower initiation (R1) up until physiological maturity (R8) for each sub-sub plot.

d. Plant height (cm): Plant height of three plants for each sub-sub plot was measured on a weekly basis up until physiological maturity. Plant height was measured from the soil surface to the highest natural point of plants. Only the final plant height will be discussed.

e. Pod clearance (cm): Pod clearance of three plants for each sub-sub plot was measured before harvesting after physiological maturity. Measurements were taken from the soil surface to the lowest point of the natural hanging pod.

4.3.2 Yield and yield components

a. Number of pods per plant: For each sub-sub plot a total of ten plant pods were sampled and counted after harvest.

b. Number of seeds per pod: Number of seeds per plant was counted and divided by the number of pods to determine the number of seeds per pod.

c. Hundred-seed weight: A hundred-seeds were counted from the harvested grain and weighed. The weight was adjusted to a moisture content of 12.5%.

d. Grain yield: Grain yield for each sub-sub plot was harvested and converted to ton per hectare and its moisture content adjusted to 12.5%.

4.3.3 Statistical analysis

Data was analysed using the statistical program SAS version 9.2® (SAS Inst., 1992). Treatment means were separated using Tukey's least significance difference (LSD) test at a 5% level of confidence.

4.4 Results and Discussion

Analysis of variance indicated that data from the 2016/17 and 2017/18 cropping seasons were not homogeneous, most probably as a result of climatic differences. Consequently, the two cropping seasons will be discussed separately.

A summary on the analysis of variance evaluating the effect of maturity group, plant density and row width on soya bean plants is provided in Table 4.4. Only maturity group affected the number of days to a specific development stage (plant to R1, R1 to R5 and R5 to R8) and total growth period significantly. The treatments had no significant effect on the number of seed per pod. Plant height, pod clearance and number of pods per plant were significantly affected by both maturity group and plant density for both seasons, except for the plant density effect on pod clearance during the 2016/17 season. Maturity group significantly affected hundred-seed weight and grain yield during the 2017/18 season, while row width also affected hundred-seed weight and grain yield, with plant density only affecting grain yield.

4.4.1 Phenological development

The number of days from plant to 50% flower initiation (R1), flower initiation to incipient seed-filling (R1-R5), incipient of seed-filling to physiological maturity (R5-R8) and total growth period will be discussed.

4.4.1.1 2016/17

Analysis of variance indicated that maturity group (MG) was the only factor that significantly influenced the number of days for each of the developing stages *viz*. plant-R1, R1-R5, R5-R8, and total growth period (Table 4.4).

Table 4.4 Summary of analysis of variance indicating the effect of treatment factors on measured plant parameters

Treatments	Days to specific development stage								Growth parameters				Yield and yield components							
	Plant-R1		R1-R5		R5-R8		Total growth period		Plant height		Pod clearance		Number of pods per plant		Number of seeds per pod		Hundred-seed weight		Grain yield	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
Maturity group (MG)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	ns	*	ns	*
Plant density (PD)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	ns	*	*	ns	ns	ns	ns	ns	*
Row width (RW)	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	*	ns	ns	*
MG X PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	*	*	ns	ns	*	*	ns	*
MG X RW	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	*	ns	ns	ns	*	ns	*
PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns	*	*	*
MG X PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	*	ns	ns	ns	*	*	ns
CV %	0.92	0.37	1.00	1.41	1.07	0.78	0.38	0.41	3.59	1.31	14.53	8.08	10.44	17.56	3.89	5.06	20.53	10.80	7.43	4.33

ns – not significant
*** - P ≤ 0.05**
CV – coefficient of variance

There were markedly significant differences between maturity groups for the number of days to R1 growth stage. MG 4.5 only took 42 days to reach R1 in comparison with 70 and 77 days for MG 5 and MG 6, respectively. In each instance the growth period was significantly different although the difference between MG 5 and MG 6 was only 7 days. This was considerably a shorter period for MG 4.5 (17 days), and longer for MG 5 (7 days) and MG 6 (7 days) than the average recommendation for each cultivar to reach R1 (Table 4.3). The number of days required to grow from R1 to R5 also produced highly significant differences. MG 4.5 and MG 5 both took 35 days, from R1 to R5, significantly less than MG 6 that took 42 days. The number of days from R5 to R8 was 42 for MG 6, which was significantly less than that of MG 4.5 and MG 5 that took 7 days (1 week) longer. There were also highly significant differences for the total growth period. MG 4.5 took the least number of days to reach physiological maturity (126 days), followed by MG 5 (154 days), while MG 6 took 161 days, significantly longer than both MG 5 and MG 4.5. For all three maturity groups the number of days to reach physiological maturity was within range, compared to the average recommendation for each cultivar, taking into consideration the dry off period of 7 to 10 days, depending on weather conditions, which needed to be added to the total growth period before harvest could commence. From this it is evident that the reduction in growth period for the specific cultivar representing MG 4.5 can only be attributed to the shorter vegetative growth period.

Table 4.5 The effect of maturity group on the number of days to flower initiation (R1), seed-fill (R1-R5), physiological maturity (R5-R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant to R1**	**R1 to R5**	**R5 to R8**	
4.5	42	35	49	126
5	70	35	49	154
6	77	42	42	161
MG $_{LSD\ (\leq 0.05)}$	1.51	0.98	1.31	1.45

4.4.1.2 2017/18

Similar to the 2016/17 cropping season, maturity group was once more the only factor that influenced the number of days for each of the developing stages *viz*. plant-R1, R1-R5 and R5-R8, and total growth period significantly, according to the analysis of variance (Table 4.4).

The number of days MG 4.5 took from plant to R1 was significantly lower (63 days), compared to that of MG 5 and MG 6, with 84 and 91 days, respectively. This was within the range for MG 4.5 according to the average recommendation for this cultivar, while for MG 5 and MG 6, the number of days required to reach R1 was considerably longer by 21 days for both. The number of days from R1 to R5 also produced significant differences for the different maturity groups. MG 4.5 and MG 5 both took 42 days from R1 to R5, significantly more than MG 6, which took only 35 days. The number of days from R5 to R8 for MG 4.5 and MG 5 was 35 days, significantly less than MG 6, which took 42 days. There were also highly significant differences for the total growth period. MG 4.5 utilised significantly fewer days to reach physiological maturity with 140 days, followed by MG 5 which took 161 days, while MG 6 took 168 days, significantly longer than both MG 4.5 and MG 5. For all three maturity groups, the number of days to reach physiological maturity was considerably longer in comparison to the average recommendation for each cultivar, taking into consideration the dry-off period of 7 to 10 days and depending on weather conditions, which needed to be added to the total growth period before harvest could commence.

Table 4.6 The effect of maturity group on the number of days to flower initiation (R1), seed-fill (R1-R5), physiological maturity (R5-R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant to R1**	**R1 to R5**	**R5 to R8**	
4.5	63	42	35	140
5	84	42	35	161
6	91	35	42	168
MG $_{LSD\ (\leq 0.05)}$	0.76	1.45	0.76	1.69

This study's results are similar to findings in Chapter 3 (see Chapter 3.4.1.2 for discussion). In contrast to this study's results Yigezu (2014) reported that the main effect of row width showed that soya beans in 0.30 m row widths flowered significantly earlier compared wider rows widths (0.40 m to 0.60 m), with days to flowering increasing with narrower row widths. Yigezu (2014) also reported that the number of days to physiological maturity tends to increase with an increase in row width from 0.30 m to 0.60 m, although this was not considered to be significant.

4.4.2 Plant height

4.4.2.1 2016/17

Plant height at physiological maturity was significantly affected by maturity group and plant density as main effect as well as the interaction effect of MG by RW (Table 4.4).

Maturity group had a significant effect on plant height. Between maturity groups there were significant differences with MG 5 recording the highest plant height (111.09 cm), followed by MG 6 (104.22 cm) and MG 4.5 (84.91 cm) (Figure 4.1). With plant density, plant height increased significantly with each increment from 100 000 plants ha^{-1} (95.40 cm) to 200 000 plants ha^{-1} (99.00 cm) to 270 000 plants ha^{-1} (101.54 cm) and finally to 400 000 plants ha^{-1} (104.38 cm) (Figure 4.2).

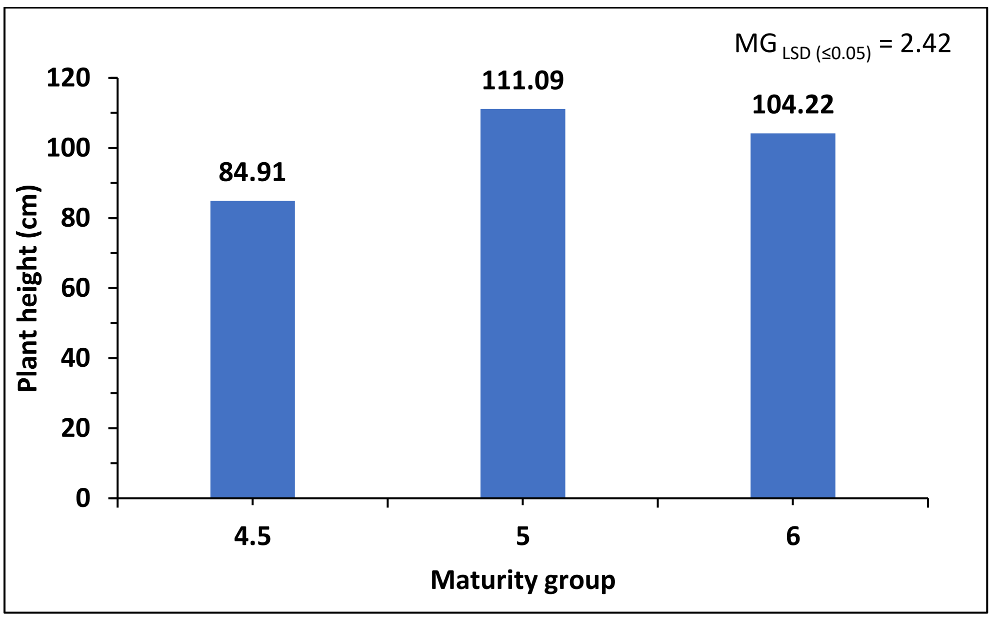

Figure 4.1 Effect of maturity group on plant height.

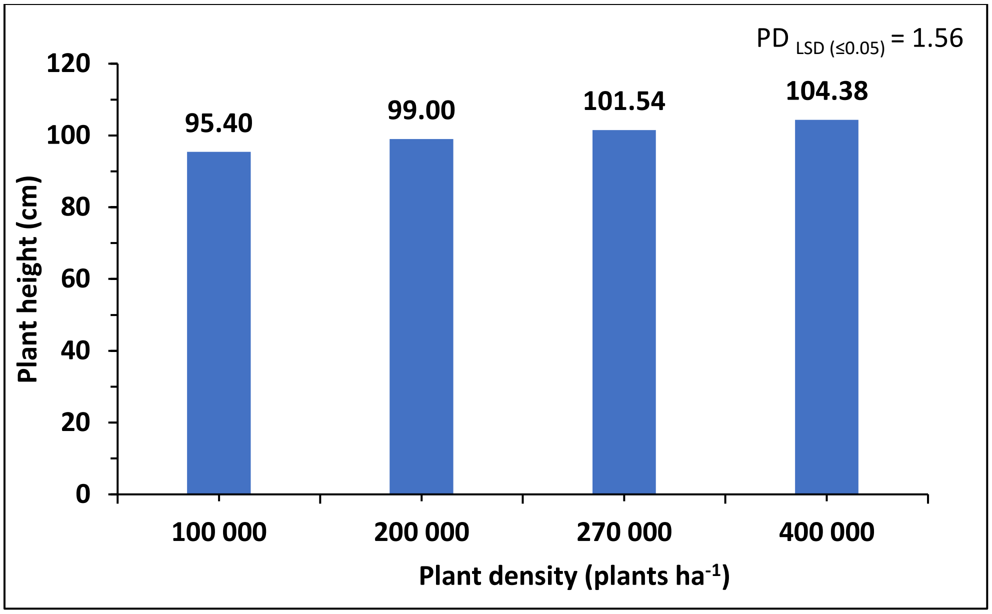

Figure 4.2 Effect of plant density on plant height.

The interaction effect of MG by RW significantly affected plant height (Table 4.7). Although plant height of plants grown in narrow rows (0.38 m) was taller than that of wide rows (0.76 m) for two of the maturity groups (MG 5 and 6), no significant differences were found. Plant height was in general less for MG 4.5, followed by MG 6, with MG 5 having the tallest plants. Maturity group was mainly the treatment factor that resulted in significant differences of plant height.

Table 4.7 Effect of maturity group and row width on plant height (cm)

Row width	Maturity group			
	4.5	5	6	Mean
0.38 m	83.56	111.13	105.19	99.96
0.76 m	86.25	111.06	103.25	100.19
Mean	84.91	111.09	104.22	

MG x RW $_{LSD\ (\leq 0.05)}$ = 4.25

4.4.2.2 2017/18

Plant height at physiological maturity was significantly affected by maturity group, plant density and row width as main effects, as well as the interaction effects of MG by PD, MG by RW and PD by RW (Table 4.4).

Maturity group significantly affected plant height. MG 6 recorded the highest plant height with 87.10 cm, followed by MG 5 with 86.97 cm, with no significant differences between MG 5 and MG 6, but both significantly higher than MG 4.5 with 78.03 cm (Figure 4.3). In terms of plant density, plant height increased significantly from 100 000 plants ha^{-1} (77.46 cm) to 200 000 plants ha^{-1} (80.63 cm), as well as to 270 000 plants ha^{-1} (86.38 cm) and 400 000 plants ha^{-1} (91.67 cm) (Figure 4.4). Row width had a significant effect on plant height with 0.76 m rows recording a significantly higher plant height (84.67 cm) compared to that of 0.38 m rows (83.40 cm) (Figure 4.5).

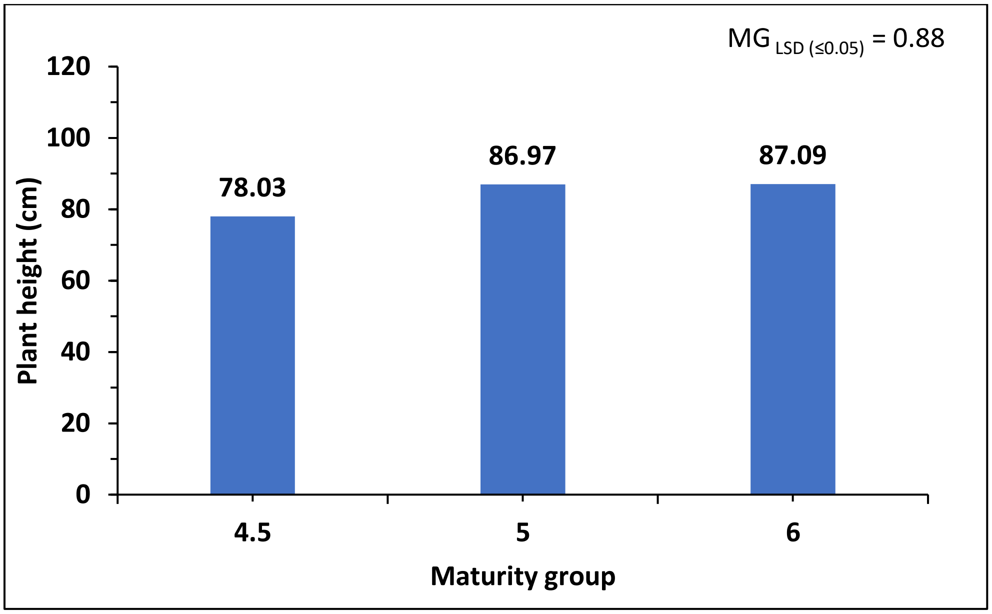

Figure 4.3 Effect of maturity group on plant height.

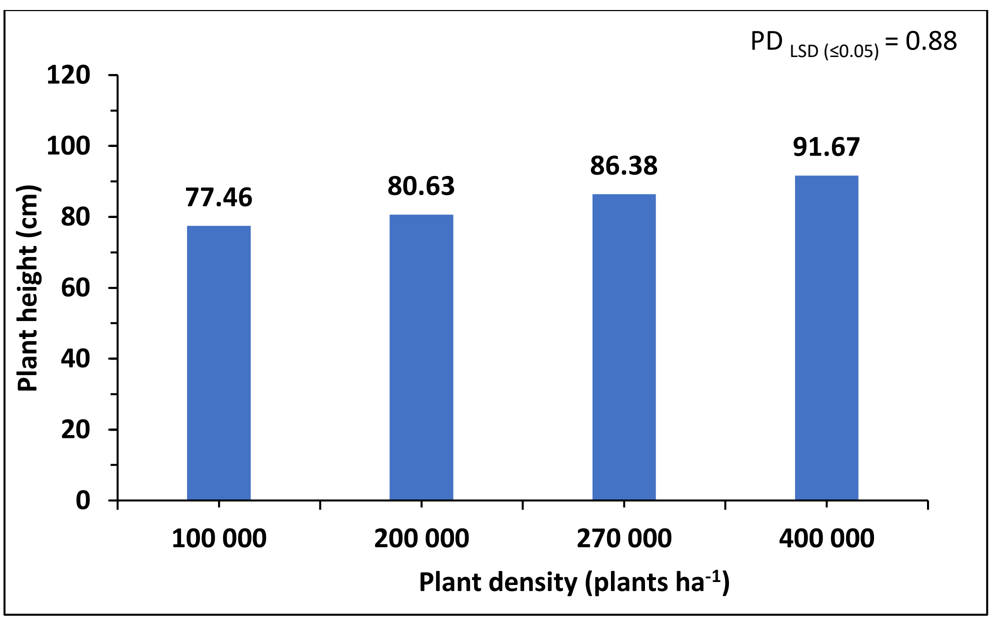

Figure 4.4 Effect of plant density on plant height.

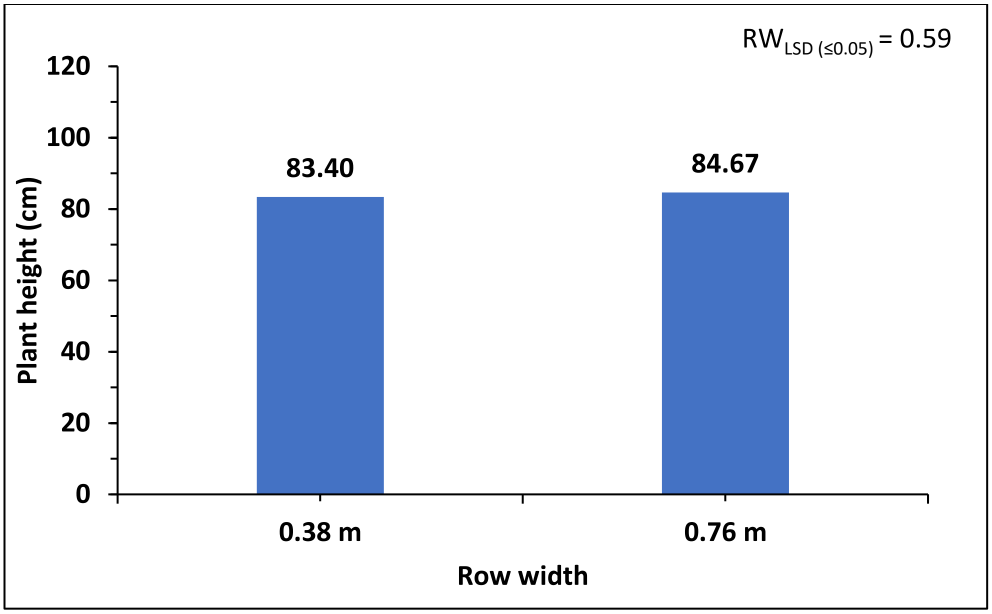

Figure 4.5 Effect of row width on plant height.

The MG by PD interaction significantly affected plant height (Table 4.8). The plant height of all three maturity groups increased significantly with each increment in plant density, and the tallest plants were measured at 400 000 plant ha^{-1}. MG 5 and MG 6 produced the tallest plants, with no significant difference between both, while both produced significantly taller plants than those of MG 4.5.

The MG by RW interaction significantly affected plant height (Table 4.9). Although the plant height of plants grown in wide rows (0.76 m) were taller than that of narrow rows (0.38 m) for all three maturity groups, there were only a significant difference within MG 4.5. The plant height of MG 4.5 at both row widths was significantly less compared to that of MG 5 and MG 6.

The PD by RW interaction significantly affected plant height. With each increment in plant density, plant height increased significantly for both row widths (Table 4.10). The plants grown at 100 000 and 200 000 plants ha^{-1} at 0.76 m rows were significantly taller compared to plants grown in 0.38 m rows, with no significant differences between row widths at 270 000 and 400 000 plants ha^{-1}. Although these differences in plant height were significant, the greatest difference was only 3%.

Table 4.8. Effect of maturity group and plant density on plant height (cm)

Plant density (plants ha^{-1})	Maturity group			
	4.5	5	6	Mean
100 000	72.63	79.25	80.50	77.46
200 000	76.13	82.63	83.13	80.63
270 000	78.13	91.13	89.88	86.38
400 000	85.25	94.88	94.88	91.67
Mean	78.03	86.97	87.09	

MG x PD $_{LSD\ (\leq 0.05)}$ = 1.91

Table 4.9 Effect of maturity group and row width on plant height (cm)

Row width	Maturity group			
	4.5	5	6	Mean
0.38 m	76.63	86.88	86.69	83.40
0.76 m	79.44	87.06	87.50	84.67
Mean	78.03	86.97	87.09	

MG x RW $_{LSD\ (\leq 0.05)}$ = 1.55

Table 4.10 Effect of row width and plant density on plant height (cm)

Plant density (plants ha^{-1})	Row width		
	0.38 m	0.76 m	Mean
100 000	76.50	78.42	77.46
200 000	79.42	81.83	80.63
270 000	86.33	86.42	86.38
400 000	91.33	92.00	91.67
Mean	83.40	84.67	

RW x PD $_{LSD\ (\leq 0.05)}$ = 1.44

For both the 2016/17 and 2017/18 season MG 5 and MG 6 recorded a significantly taller plant height compared to MG 4.5. In both seasons plant height increased significantly with each increment increase in plant density. During the 2017/18 season 0.76 m rows recorded a significantly taller plant height compared to 0.38 m rows, but this effect was not as profound as the effect which maturity group and plant density had on plant height.

This study's results were similar to the findings in Chapter 3 (see Chapter 3.4.2.2 for discussion), with the only exception, MG 4.5 recording significantly the shortest plant height in this study compared to MG 5 in Chapter 3. In agreement with this study, both Osman (2011), Cox and Cherney (2011) and Yigezu (2014) reported that the row width as main effect had a significant effect on plant height, but both reported that plant height decreased with increasing row width, which contrasts with the findings in this study. In this study, row width did affect plant height significantly, with plant height increasing with an increase in row width, but with minor differences (<3%). In contrast, De Bruin and Pedersen (2008b) and Khubele (2015) reported that row width had no significant effect on plant height, as well as the interaction effect between maturity group and row width.

4.2.3 Pod clearance

4.2.3.1 2016/17

Pod clearance was significantly affected by both maturity group and plant density as main effect (Table 4.4).

Pod clearance increased significantly from MG 4.5 (8.50 cm) to MG 5 (19.97 cm) as well as to MG 6 (27.84 cm) (Figure 4.6). Similarly, pod clearance increased with an increase in plant density. The effect, however, was not as profound, with pod clearance increasing from 17.33 cm at 100 000 plants ha^{-1} to 20.17 cm at 400 000 plants ha^{-1}, which constituted the only significant difference (Figure 4.7).

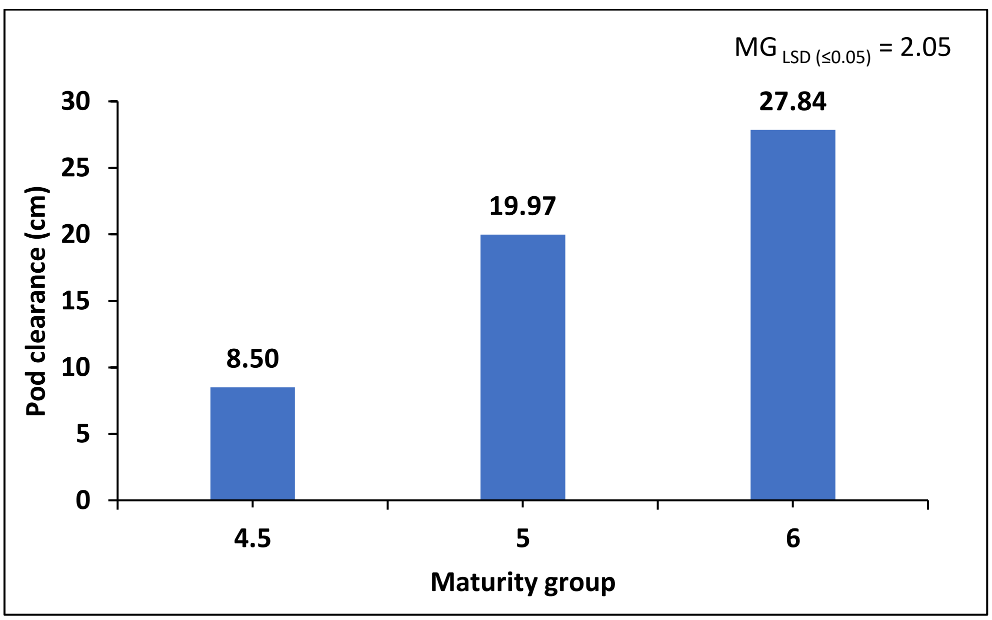

Figure 4.6 Effect of maturity group on pod clearance.

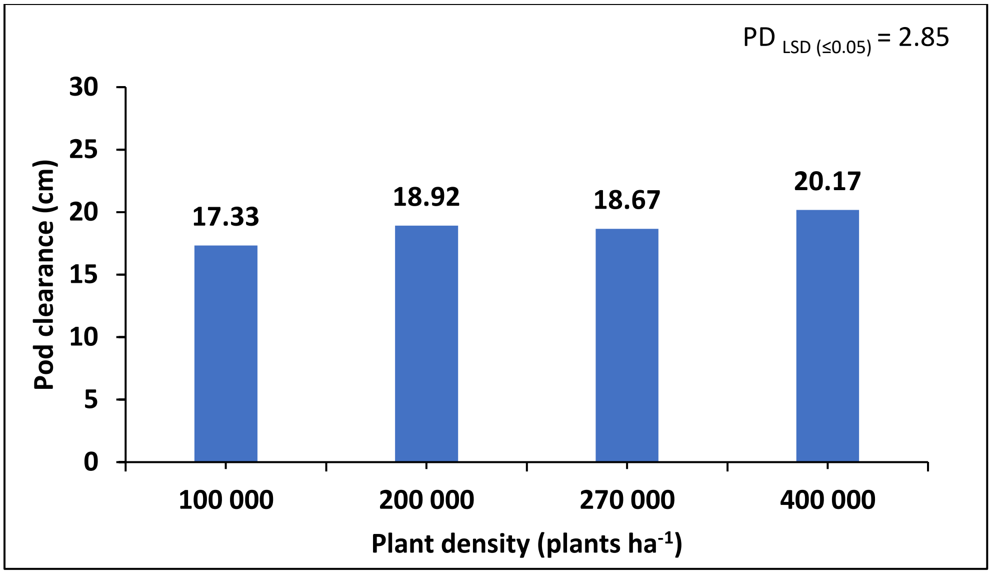

Figure 4.7 Effect of plant density on pod clearance.

4.2.3.2 2017/18

Pod clearance was significantly affected by the main effects of maturity group and row width, as well as the interaction effect of MG by PD (Table 4.4).

Pod clearance increased significantly from MG 4.5 (8.47 cm) to MG 5 (19.47 cm), as well as to MG 6 (29.31 cm) (Figure 4.8). Row width also resulted in a significant effect on pod clearance, with 0.76 m rows recording the highest pod clearance (19.50 cm) compared to that of 0.38 m rows (18.67 cm) (Figure 4.9).

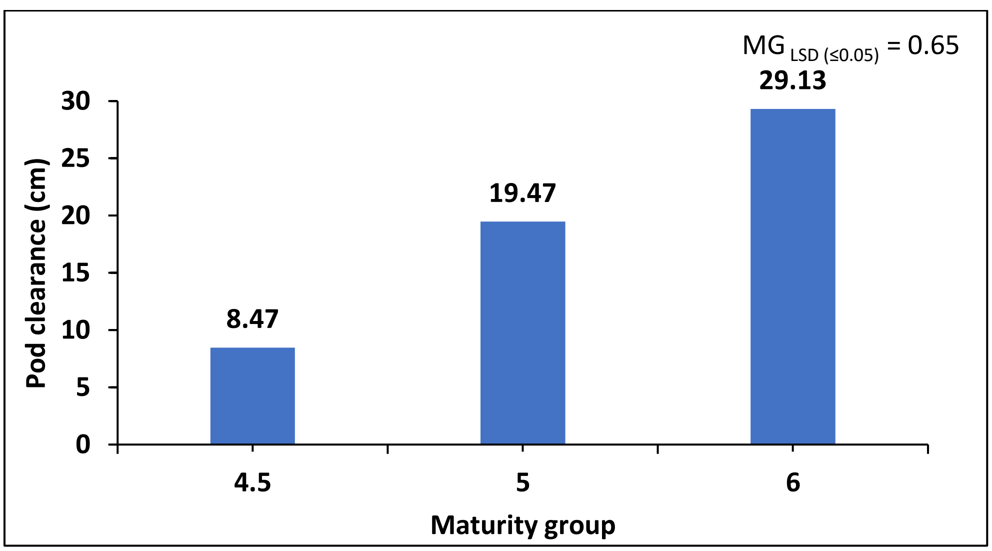

Figure 4.8 Effect of maturity group on pod clearance.

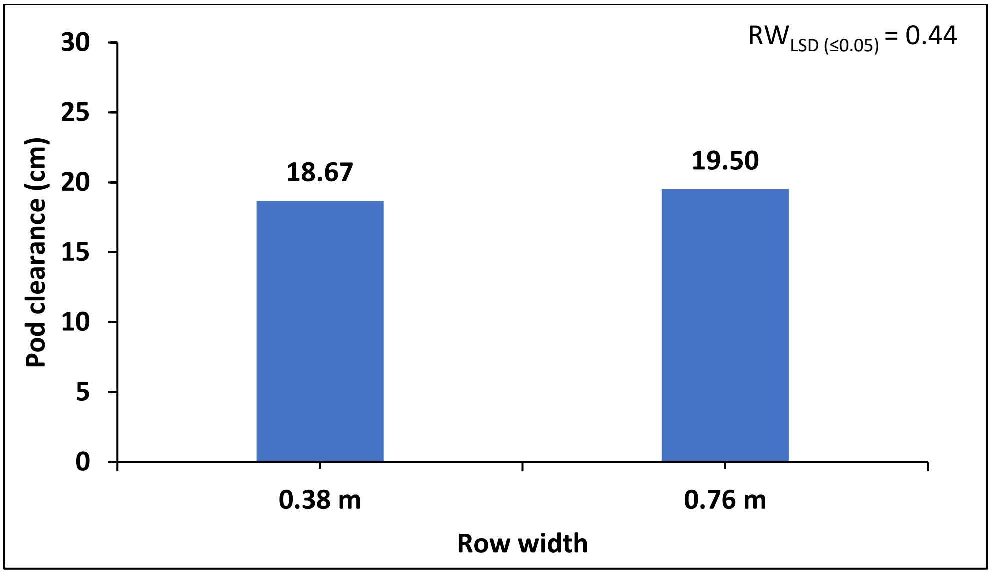

Figure 4.9 Effect of row width on pod clearance.

The MG by PD interaction significantly affected pod clearance (Table 4.11). With the exception of MG 6, no significant differences were obtained within maturity groups at different plant densities. Within MG 6 the pod clearance of 270 000 plants ha^{-1} (30.75 cm) was the highest, and was significantly higher than both 100 000 plants ha^{-1} (27.88 cm) as well as 200 000 plants ha^{-1} (28.50 cm). The pod clearance of plants at MG 6 cultivated at 400 000 plants ha^{-1} (30.13 cm) was not significantly different from that of 270 000 plants ha^{-1}, but was significantly higher than that of 100 000 plants ha^{-1}. Of all the factors selected, maturity group once more proved to have the greatest effect on pod clearance.

Table 4.11 Effect of maturity group and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
100 000	8.25	20.38	27.88	18.83
200 000	8.75	18.50	28.50	18.58
270 000	8.50	20.00	30.75	19.75
400 000	8.38	19.00	30.13	19.17
Mean	8.47	19.47	29.31	

MG x $PD_{LSD\ (\leq 0.05)}$ = 1.98

This study's results were similar to the findings in Chapter 3 (see Chapter 3.4.2.2 for discussion). In this study, maturity group had significantly the greatest effect on pod clearance while plant density and row width also had an effect, albeit negligible.

4.2.4 Number of pods per plant

4.2.4.1 2016/17

The number of pods per plant was significantly affected by the main effects of maturity group and plant density as well as the interaction effect of MG by PD (Table 4.4).

Maturity group significantly affected the number of pods per plant where MG 6 recorded the greatest number of pods per plant (60.51), followed by MG 4.5 (58.94), with only MG 6 significantly more than MG 5 (51.14) (Figure 4.10). The number of pods per plant decreased significantly from 100 000 plants ha^{-1} (79.33) to 200 000 plants ha^{-1} (55.59). From 200 000 plants ha^{-1} to 270 000 plants ha^{-1} (51.77) the number of pods per plant also decreased, but not significantly, while a significant decrease from 270 000 plants ha^{-1} to 400 000 plants ha^{-1} (40.763) was recorded (Figure 4.11).

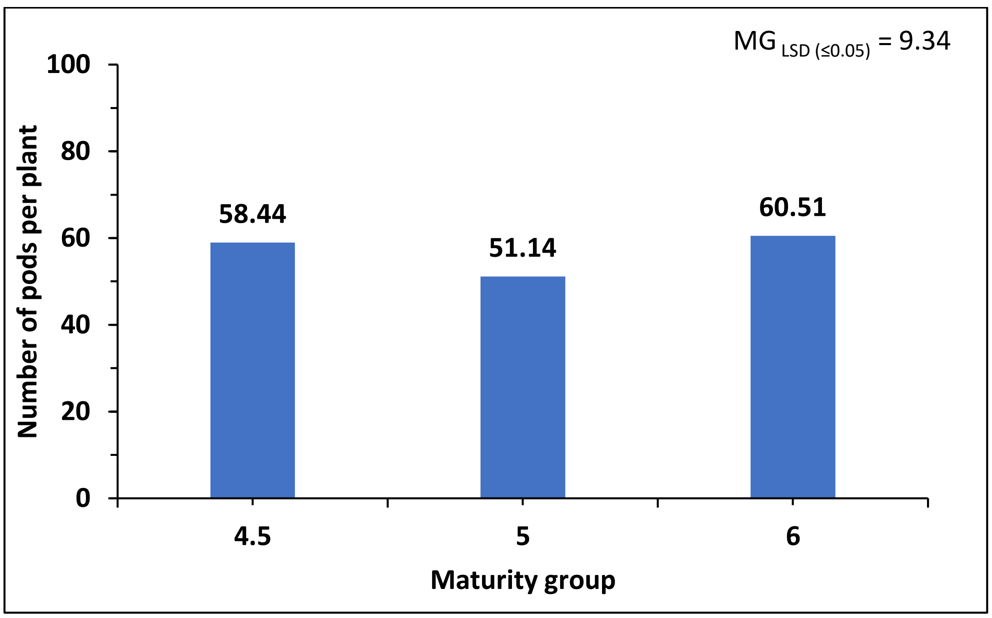

Figure 4.10 Effect of maturity group on the number of pods per plant.

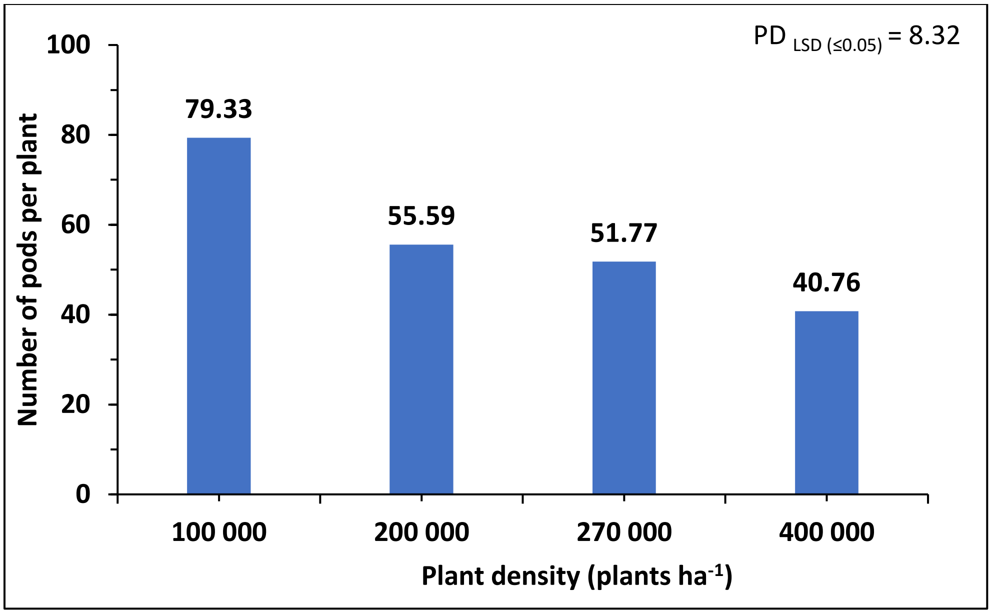

Figure 4.11 Effect of plant density on the number of pods per plant.

The MG by PD interaction significantly affected the number of pods per plant (Table 4.12). In general, the number of pods per plant decreased with each increment in plant density. Within each maturity group, the highest number of pods per plant were recorded at 100 000 plants ha^{-1}. Significant differences were obtained within MG 4.5, between 100 000 plants ha^{-1} (77.11) and 400 000 plants ha^{-1} (47.91). Within MG 5, 100 000 plants ha^{-1} recorded significantly the greatest number of pods per plant, while within MG 6, 100 000 plants ha^{-1} also recorded the significantly greatest number of pods per plant with 200 000 plants ha^{-1}, recording a significantly greater number of pods per plant than 400 000 plants ha^{-1}. Between maturity groups, within 100 000 plants ha^{-1}, MG 6 recorded the greatest number of pods per plant (91.09), followed by MG 4.5 (77.11). MG 5 (69.80) had significantly fewer number of pods per plant compared to MG 6. Within 200 000 plants ha^{-1}, MG 6 recorded the greatest number of pods per plant (63.91), followed by MG 5 (51.86) and MG 4.5 (50.99) with no significant difference in number of pods per plant. Within 270 000 plants ha^{-1} and 400 000 plants ha^{-1}, the greatest number of pods per plant were obtained at MG 4.5, followed by MG 6 and MG 5. There were also no significant differences in number of pods per plant with regard to each of these plant densities.

Table 4.12 Effect of maturity group and plant density on the number of pods per plant

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
100 000	77.11	69.80	91.09	79.33
200 000	50.99	51.86	63.91	55.59
270 000	59.76	47.74	47.81	51.77
400 000	47.91	35.15	39.23	40.76
Mean	58.94	51.14	60.51	

MG x PD $_{LSD\ (\leq 0.05)}$ = 17.20

4.2.4.2 2017/18

The number of pods per plant was significantly affected by the main effects of maturity group and plant density as well as the interaction effects of MG by PD, MG by RW and PD by RW (Table 4.4).

Maturity group significantly affected number of pods per plant, with MG 6 recording the highest number of pods per plant (72.25), followed by MG 5 (70.77), both significantly greater than MG 4.5 (61.71) (Figure 4.12). For plant density, number of pods per plant decreased significantly from 100 000 plants ha^{-1} (85.06) to 200 000 plants ha^{-1} (69.55). From 200 000 plants ha^{-1} to 270 000 plants ha^{-1} (66.16) number of pods per plant decreased but not significantly, while from 270 000 plants ha^{-1} to 400 000 plants ha^{-1} (52.20) the number of pods per plant showed a significant decrease (Figure 4.13).

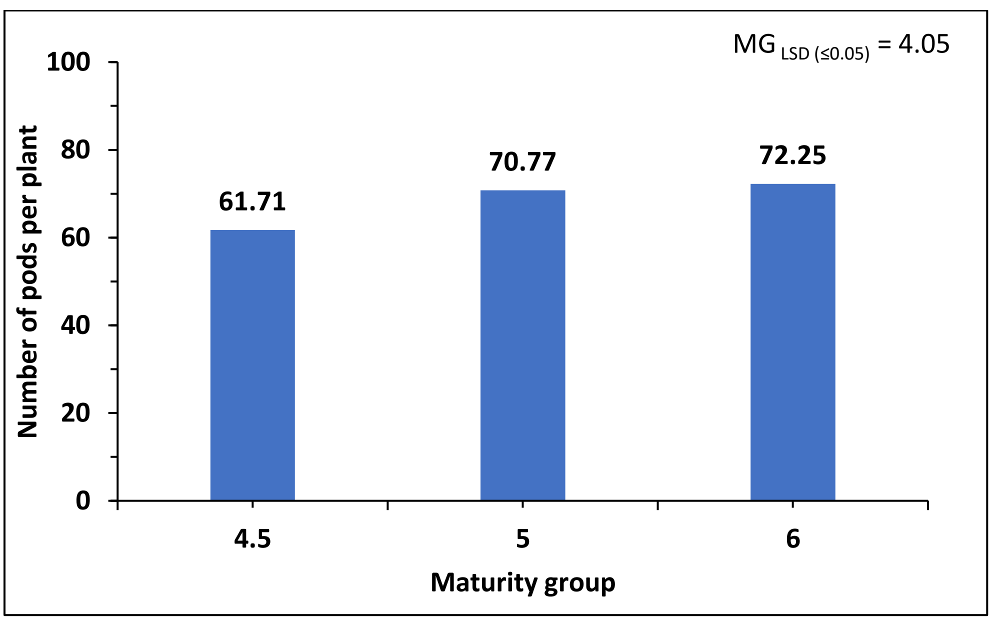

Figure 4.12 Effect of maturity group on the number of pods per plant.

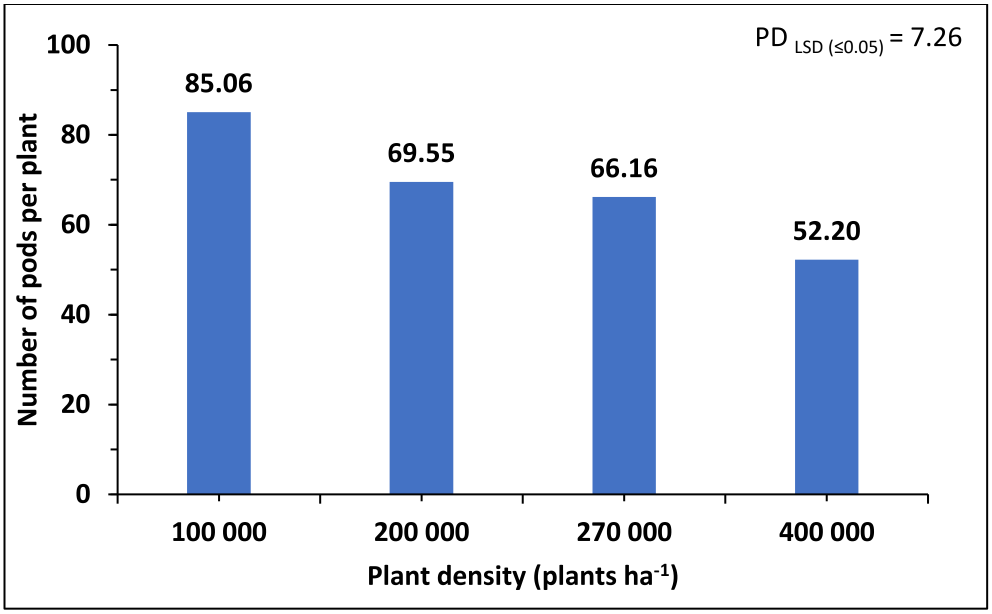

Figure 4.13 Effect of plant density on the number of pods per plant.

The MG by PD interaction significantly affected number of pods per plant (Table 4.13). In general, number of pods per plant decreased significantly with each increment in plant density within all three maturity groups. Within each plant density increment, the greatest number of pods per plant was recorded for 100 000 plants ha^{-1} at MG 6, while for 200 000, 270 000 and 400 000 plants ha^{-1}, the greatest number of pods per plant was recorded at MG 5. Within each plant density increment, the only significant difference obtained was at 100 000 plants ha^{-1} with MG 6 recording a significantly greater number of pods per plant (102.45) than both MG 4.5 (72.95) and MG 5 (79.78). In general, plants of MG 4.5 recorded the least number of pods per plant, except for 400 000 plants ha^{-1}, where MG 6 recorded the lowest pod number per plant. Within MG 4.5, the only significant difference in number of pods per plant was obtained between 100 000 plants ha^{-1} (72.95) and 400 000 plants ha^{-1} (49.08). Within MG 5 both 100 000 plants ha^{-1} (79.78) and 200 000 plants ha^{-1} (72.78) recorded a significantly greater number of pods per plant than that of 400 000 plants ha^{-1} (59.73). Within MG 6, 100 000 plants ha^{-1} (102.45) recorded significantly the greatest number of pods per plant, while 200 000 plants ha^{-1} (72.23) and 270 000 plants ha^{-1} (66.53) recorded a significantly greater number of pods per plant that than of 400 000 plants ha^{-1} (47.80).

The MG by RW interaction significantly affected the number of pods per plant (Table 4.14). Between row widths, 0.76 m rows recorded the greatest number of pods per plant for both MG 4.5 and MG 6, while for MG 6, 0.38 m rows recorded a greater number of pods per plant than that of 0.76 m rows. There was no significant difference between row widths within each maturity group. The only significant differences in number of pods per plant were between each maturity group within both row width treatments. Number of pods per plant significantly increased from MG 4.5 to MG 5 for both row widths and from MG 5 to MG 6 for the 0.38 m rows. From MG 5 to MG 6 at the 0.76 rows, there was a decrease in pod number with no significant difference.

The PD by RW interaction significantly affected the number of pods per plant (Table 4.15). The greatest number of pods per plant was recorded at 100 000 plants ha^{-1} in rows 0.38 m apart (96.37). This was significantly greater than all other treatment combinations. Between row widths, the 0.38 m rows recorded the greatest number of pods per plant at 100 000 and 200 000 plants ha^{-1}, while the 0.76 m rows recorded the greatest number of pods per plant at 270 000 and 400 000 plants ha^{-1}. The only significant difference in number of pods per plant between row width was recorded at 100 000 and 400 000 plants ha^{-1}. Within the 0.38 m row width, the number of pods per plant generally decreased significantly with each increment in plant density. This was not observed in the 0.76 m row width. The only significant difference in number of pods per plant within the 0.76 m rows was found between that of 100 000 plants ha^{-1} (73.75) and 400 000 plants ha^{-1} (63.15).

Table 4.13 Effect of maturity group and plant density on the number of pods per plant

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
100 000	72.95	79.78	102.45	85.06
200 000	63.65	72.78	72.23	69.55
270 000	61.15	70.80	66.53	66.16
400 000	49.08	59.73	47.80	52.20
Mean	61.71	70.77	72.25	

MG x PD $_{LSD\ (\leq 0.05)}$ = 12.37

Table 4.14 Effect of maturity group and row width on the number of pods per plant

Row width	**Maturity group**			
	4.5	**5**	**6**	**Mean**
0.38 m	60.43	69.08	76.81	68.77
0.76 m	62.99	72.46	69.69	67.71
Mean	61.71	70.77	72.25	

MG x RW $_{LSD\ (\leq 0.05)}$ = 7.13

Table 4.15 Effect of row width and plant density on the number of pods per plant

Plant density (plants ha^{-1})	Row width		
	0.38 m	**0.76 m**	**Mean**
100 000	96.37	73.75	85.06
200 000	73.30	65.80	69.55
270 000	64.17	68.15	66.16
400 000	41.25	63.15	52.20
Mean	68.77	67.71	

RW x PD $_{LSD (\leq 0.05)}$ = 9.31

This study's results are similar to the findings in Chapter 3 with regard to plant density (See chapter 3.4.4.2 for discussion). However, in this study, maturity group also had a significant effect on number of pods per plant, while the effect of row width was not profound. In agreement with this study Osman (2011), Yigezu (2014) and Khubele (2015) reported that different maturity groups resulted in significant differences in the number of pods per plant. Yigezu (2014) and Khubele (2015) also reported that row width significantly affected the number of pods per plant, with the number of pods per plant decreasing with increasing row widths, which is in contradiction to this study. This study shows that the number of pods per plant both decreased (at 100 000 and 200 000 plants ha^{-1}) and increased (at 270 000 and 400 000 plants ha^{-1}) with an increase in row width. By contrast, Osman (2011) reported that row width had no significant effect on number of pods per plant.

Plant density proved to have the greatest effect on number of pods per plant. Generally, with each increment in plant density, number of pods per plant decreased significantly. Maturity group and row width had a significant effect on number of pods per plant, but this was not as profound as was the case with plant density. It is argued that the increased plant density contributes to increased competition between plants for nutrients, moisture, and sunlight. Hence this result in lower number of pods per plant with increasing plant densities. This might also be due to the development and vigorous leaf growth of low plant densities and improved photosynthetic efficiency, resulting in a larger number of pods per plant. This agrees with Abdel (2008) and Lopez-Bellido *et al*., (2005) who state that soya beans, common bean and faba bean display considerable plasticity in response to varying plant densities, especially to the number of pods per plant.

4.2.5 Number of seeds per pod

4.2.5.1 2016/17 and 2017/18

Analysis of variance indicated that the interaction effect of maturity group, plant density and row width resulted in no significant differences in number of seeds per pod for both the 2016/17 and 2017/18 season. The number of seeds per pod was also not significantly affected by either one of the main effects for both seasons. (Data not shown). This result is similar to the findings discussed in Chapter 3 (see Chapter 3.4.5 for discussion).

4.2.6 Hundred-seed weight

4.2.6.1 2016/17

Hundred-seed weight was significantly affected by row width as main effect as well as the MG by PD interaction effect (Table 4.4).

Hundred-seed weight was significantly affected by row width with 0.76 m rows recording the greatest hundred-seed weight with 17.54 g, significantly greater than the 0.38 m rows with 15.33 g (Figure 4.14).

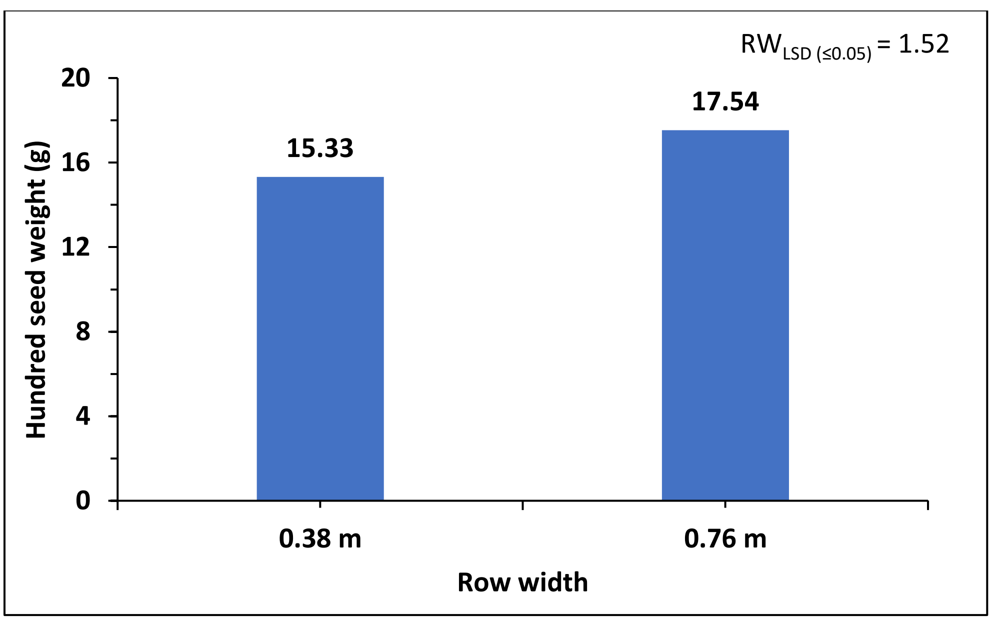

Figure 4.14 Effect of row width on the hundred-seed weight (g).

The MG by PD interaction significantly affected hundred-seed weight (Table 4.16). The only significant difference in hundred-seed weight was found within MG 4.5 between 200 000 plants ha^{-1} (19.93 g) and 400 000 plants ha^{-1} (13.72 g). No clear trend was established on what affected hundred-seed weight more between each maturity group and plant density, and within each maturity group and plant density.

Table 4.16 Effect of maturity group and plant density on the hundred-seed weight (g)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
100 000	17.55	17.98	16.07	17.20
200 000	19.93	16.53	16.18	17.55
270 000	14.42	14.78	17.27	15.49
400 000	13.72	16.06	16.69	15.49
Mean	16.40	16.34	16.55	

MG x PD $_{LSD\ (\leq 0.05)}$ = 5.81

4.2.6.2 2017/18

Hundred-seed weight was significantly affected by the main effect of maturity group as well as the interaction effect of MG by PD, MG by RW and PD by RW.

Hundred-seed weight was significantly affected by maturity group with MG 4.5 recording a significantly greater hundred-seed weight (15.05 g) than both MG 5 (11.08 g) and MG 6 (12.84 g), of which the latter two also differed significantly (Figure 4.15).

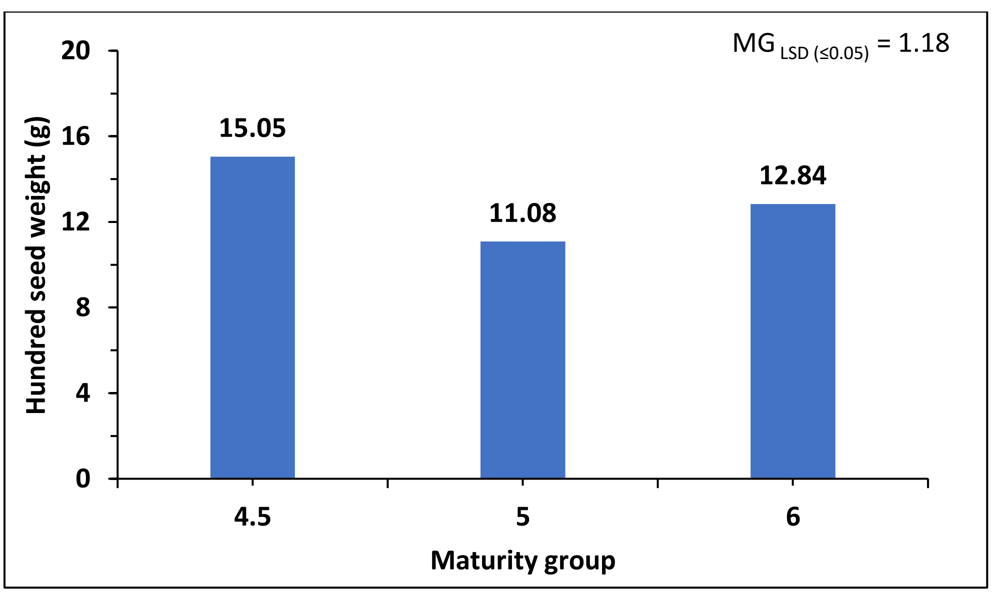

Figure 4.15 Effect of maturity group on the hundred-seed weight (g).

The MG by PD interaction affected hundred-seed weight significantly (Table 4.17). MG 4.5 generally recorded significantly the greatest hundred-seed weight, except for 200 000 and 400 000 plants ha^{-1} where it was greater than MG 6 but not significantly. MG 6 recorded a greater hundred-seed weight compared to that of MG 5, with only a significant difference at 200 000 plants ha^{-1}. Within MG 4.5 and MG 6, 100 000 and 200 000 plants ha^{-1} recorded a greater hundred-seed weight than that of 270 000 plants ha^{-1} and 400 000 plants ha^{-1}. Within each maturity group there were no significant differences in hundred-seed weight between each plant density increment, except within MG 6 between 200 000 plants ha^{-1} (14.34 g) and 270 000 plants ha^{-1} (11.47 g).

The MG by RW interaction affected hundred-seed weight significantly (Table 4.18). At both 0.38 m and 0.76 m rows MG 4.5 recorded the greatest hundred-seed weight of 14.53 g and 15.57 g, respectively, which were significantly greater than that of MG 5 (11.49 and 10.67 g, respectively) and significantly greater than that of MG 6 at 0.38 m rows (11.95 g) only. There was also a significant difference in the hundred-seed weight between MG 5 and MG 6 in 0.76 m rows, with 10.67 g and 13.73 g respectively. Within each maturity group and between row widths there were no significant differences in the hundred-seed weight.

The PD by RW interaction affected hundred-seed weight significantly (Table 4.19). Within each plant density increment between row widths, plants grown in 0.76 m rows recorded a greater hundred-seed weight at 100 000 (14.38 g), 270 000 (13.24 g) and 400 000 plants ha^{-1} (13.17 g), while at 200 000 plants ha^{-1} (14.04 g) the 0.38 m rows recorded a greater hundred-seed weight. Within the 0.38 m rows 200 000 plants ha^{-1} recorded the greatest hundred-seed weight while within the 0.76 m rows 100 000 plants ha^{-1} recorded the greatest hundred-seed weight. Although there were significant differences between plant densities no clear trend was observed.

Table 4.17 Effect of maturity group and plant density on the hundred-seed weight (g)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
100 000	16.01	11.96	12.98	13.65
200 000	15.37	10.12	14.34	13.28
270 000	14.93	11.37	11.47	12.59
400 000	13.90	10.87	12.56	12.44
Mean	15.05	11.08	12.84	

MG x PD $_{LSD\ (\leq 0.05)}$ = 2.42

Table 4.18 Effect of maturity group and row width on the hundred-seed weight (g)

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
0.38 m	14.53	11.49	11.95	12.66
0.76 m	15.57	10.67	13.73	13.32
Mean	15.05	11.08	12.84	

MG x RW $_{LSD\ (\leq 0.05)}$ = 2.08

Table 4.19 Effect of row width and plant density on the hundred-seed weight (g)

Plant density (plants ha^{-1})	Row width		
	0.38 m	**0.76 m**	**Mean**
100 000	12.92	14.38	13.65
200 000	14.04	12.51	13.28
270 000	11.95	13.24	12.59
400 000	11.72	13.17	12.44
Mean	12.66	13.32	

RW x PD $_{LSD\ (\leq 0.05)}$ = 1.82

Hundred-seed weight was significantly affected by the main effect of row width during the 2016/17 season only, while during the 2017/18 season maturity group had the greatest effect on hundred-seed weight with the effect of plant density not as profound. This study's results differ from the findings in chapter 3.

In agreement with this study's results Yigezu (2014) and Matsuo (2018) reported that the main effect of maturity group had highly significant effects on hundred-seed weight, which are in agreement with the 2017/18 season's results. In contrast to this study, Osman (2011) reported that soya bean maturity group and row width had no significant effect on hundred-seed weight. Board (2000) reported that hundred-seed weight was not affected by plant density, while Mellendorf (2011) also found that plant density did not affect hundred-seed weight significantly. Yigezu (2014) and Matsuo *et al*., (2018) also reported that hundred-seed weight decreased significantly with increasing plant densities.

4.2.7 Yield (t ha^{-1})

4.2.7.1 2016/17

Grain yield was significantly affected by the PD x RW interaction (Table 4.4 and 4.20). Between row widths the plants grown in 0.38 m rows recorded the greatest grain yield at all plant densities, except at 100 000 plants ha^{-1} where plants grown in 0.76 m rows recorded the greatest grain yield. Within the 0.38 m rows the greatest grain yield was recorded at 200 000 plants ha^{-1} (4.76 t ha^{-1}) followed by 400 000 plants ha^{-1} (4.60 t ha^{-1}) and 270 000 plants ha^{-1} (4.51 t ha^{-1}), with only 200 000 and 400 000 plants ha^{-1} significantly greater than 100 000 plants ha^{-1} (4.09 t ha^{-1}). Within the 0.76 m rows 270 000 plants ha^{-1} (4.41 t ha^{-1}) recorded the greatest grain yield followed by 400 000 plants ha^{-1} (4.35 t ha^{-1}), 100 000 plants ha^{-1} (4.30 ha^{-1}) and 200 000 plants ha^{-1} (4.20 t ha^{-1}) with no significant difference between plant densities.

Table 4.20 Effect of row width and plant density on the grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Row width		
	0.38 m	**0.76 m**	**Mean**
100 000	4.09	4.30	4.20
200 000	4.76	4.24	4.50
270 000	4.51	4.41	4.46
400 000	4.60	4.35	4.47
Mean	4.49	4.32	

RW x PD $_{LSD\ (\leq 0.05)}$ = 0.42

4.2.7.2 2017/18

Grain yield was significantly affected by the main effects of maturity group, plant density and row width as well as the interaction effect of MG by PD, MG by PW and PD by RW.

Grain yield was significantly affected by maturity group with MG 6 recording significantly the greatest grain yield (3.54 t ha^{-1}), followed by MG 4.5 (3.32 t ha^{-1}) and MG 5 (3.14 t ha^{-1}), with no significant difference between the latter two (Figure 4.16). For plant density, grain yield increased slightly with increasing plant density, from 100 000 plants ha^{-1} (3.25 t ha^{-1}) and 200 000 plants ha^{-1} (3.25 t ha^{-1}) to 270 000 plants ha^{-1} (3.29 t ha^{-1}), with 400 000 plants ha^{-1} recording the significantly greatest grain yield (3.54 t ha^{-1}) compared to all the other plant densities (Figure 4.17). For row width, the 0.38 m rows recorded the greatest grain yield (3.51 t ha^{-1}), significantly greater compared to that of 0.76 m rows (3.16 t ha^{-1}) (Figure 4.18).

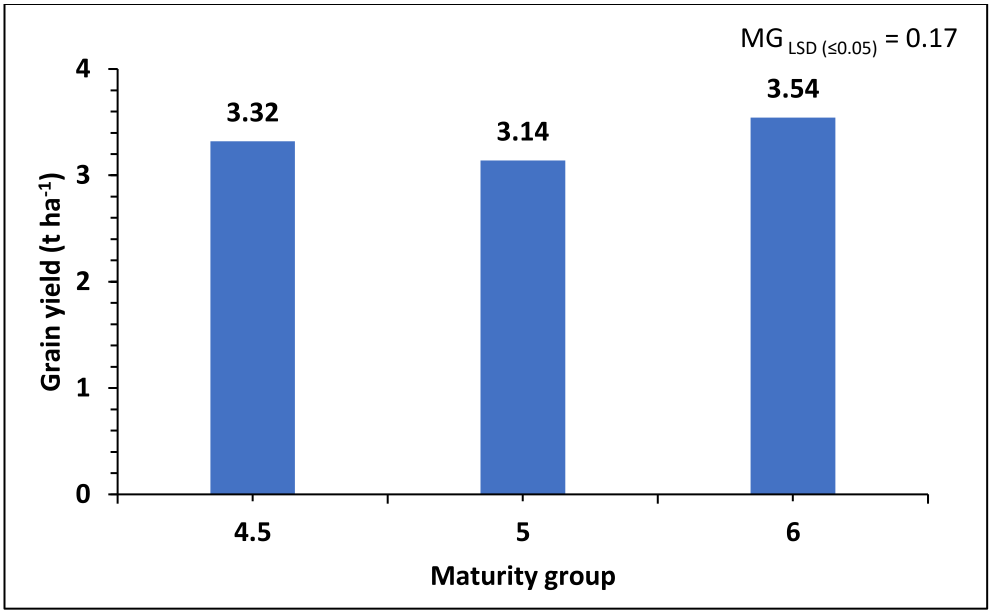

Figure 4.16 Effect of maturity group on the grain yield (t ha^{-1}).

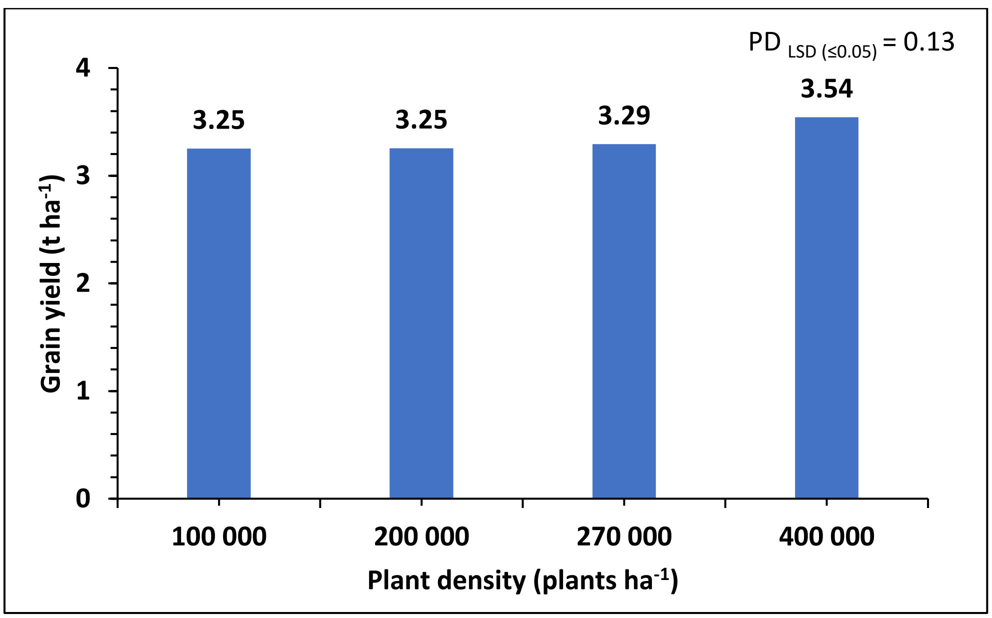

Figure 4.17 Effect of plant density on the grain yield (t ha^{-1}).

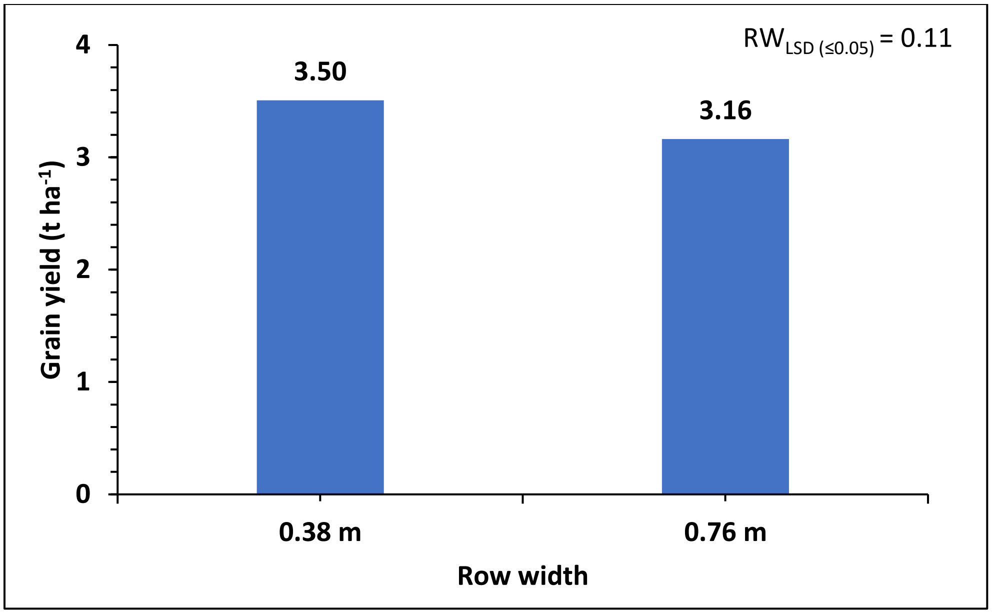

Figure 4.18 Effect of row width main effect on the grain yield (t ha^{-1}).

The MG by PD interaction significantly affected grain yield (Table 4.21). Within each maturity group the greatest grain yield was recorded at 400 000 plants ha^{-1}. There were significant differences in grain yield at MG 4.5: between 400 000 plants ha^{-1} (3.47 t ha^{-1}) and 200 000 plants ha^{-1} (3.20 t ha^{-1}), at MG 5 between 400 000 plants ha^{-1} (3.48 t ha^{-1}) and both 100 000 (2.87 t ha^{-1}) and 200 000 plants ha^{-1} (2.93 t ha^{-1}), and at MG 6 between both 400 000 (3.68 t ha^{-1}) and 200 000 plants ha^{-1} (3.63 ha^{-1}) and 270 000 plants ha^{-1} (3.36 ha^{-1}). Within each plant density group, MG 6 recorded the greatest grain yield. Within 100 000 plants ha^{-1} both MG 6 (3.50 t ha^{-1}) and MG 4.5 (3.38 t ha^{-1}) recorded a significantly greater grain yield than that of MG 5 (2.87 t ha^{-1}). Within 200 000 plants ha^{-1} MG 6 (3.63 t ha^{-1}) recorded a significantly greater grain yield compared to MG 4.5 (3.20 t ha^{-1}) and MG 5 (2.93 ha^{-1}), with a significant difference also between the latter two. Within 270 000 and 400 000 plants ha^{-1} there were no significant differences in grain yield between maturity groups.

The MG by RW interaction significantly affected grain yield (Table 4.22). Between row widths the greatest grain yield was recorded at 0.38 m rows for all three maturity groups. At both MG 5 and MG 6, the 0.38 m rows recorded a significantly greater grain yield compared to that of the 0.76 m rows. Within the 0.38 m rows, MG 6 recorded significantly the greatest grain yield (3.74 t ha^{-1}), followed by MG 4.5 (3.41 t ha^{-1}) and MG 5 (3.38 t ha^{-1}) with no significant difference in grain yield between the latter two. Within the

0.76 m rows MG 6 recorded the greatest grain yield (3.35 t ha^{-1}), followed by MG 4.5 (3.23 t ha^{-1}) and MG 5 (2.90 t ha^{-1}), with the only significant difference in grain yield evidenced between MG 6 and MG 5.

The PD by RW interaction significantly affected grain yield (Table 4.23). Between row widths at each plant density the plants grown in 0.38 m rows recorded greater grain yields compared to that of 0.76 m rows, with significantly greater grain yields at 200 000, 270 000 and 400 000 plants ha^{-1}. Within each row width, grain yield was significantly the greatest at 400 000 plants ha^{-1}. Within 0.38 m rows, grain yield increased with each increment in plant density from 100 000 plants ha^{-1} (3.34 ha^{-1}) to 200 000 plants ha^{-1} (3.46 t ha^{-1}) to 270 000 plants ha^{-1} (3.52 t ha^{-1}) and 400 000 plant ha^{-1} (3.71 t ha^{-1}). Within 0.76 m rows, grain yield decreased from 100 000 plants ha^{-1} (3.16 t ha^{-1}) to 200 000 plants ha^{-1} (3.05 t ha^{-1}), whereafter grain yield increased to 270 000 plants ha^{-1} (3.07 t ha^{-1}) and 400 000 plants ha^{-1} (3.37 t ha^{-1}).

Table 4.21 Effect of maturity group and plant density on the grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Maturity group			
	4.5	5	6	Mean
100 000	3.38	2.87	3.50	3.25
200 000	3.20	2.93	3.63	3.25
270 000	3.23	3.29	3.36	3.29
400 000	3.47	3.48	3.68	3.54
Mean	3.32	3.14	3.54	

MG x PD $_{LSD\ (\leq 0.05)}$ = 0.25

Table 4.22 Effect of maturity group and row width on the grain yield (t ha^{-1})

Row width	Maturity group			
	4.5	5	6	Mean
0.38 m	3.41	3.38	3.74	3.51
0.76 m	3.23	2.90	3.35	3.16
Mean	3.32	3.14	3.54	

MG x RW $_{LSD\ (\leq 0.05)}$ = 0.30

Table 4.23 Effect of row width and plant density on the grain yield (t ha^{-1})

Plant density (plants ha^{-1})	**Row width**		
	0.38 m	**0.76 m**	**Mean**
100 000	3.34	3.16	3.25
200 000	3.46	3.05	3.25
270 000	3.52	3.07	3.29
400 000	3.71	3.37	3.54
Mean	3.51	3.16	

RW x PD $_{LSD\ (\leq 0.05)}$ = 0.19

Grain yield was significantly affected by plant density during the 2016/17 season, while maturity group and row width had no effect. During the 2017/18 season, all treatment combinations had a significant effect on grain yield, with MG 6 recording significantly the greatest grain yield, followed by MG 4.5, and MG 5 with significantly the lowest grain yield. Grain yield showed a slightly increased tendency with increased plant density, and 0.38 m rows recorded a significantly greater grain yield compared to 0.76 m rows. This study's results for the 2016/17 season differed slightly from the findings in Chapter 3, while the results of the 2017/18 season are similar (see Chapter 3 for discussion).

Yigezu (2014) reported that differences in plant density resulted in significant differences in grain yield, but with no definite trend, while narrower row width resulted in significantly greater grain yields. Malek *et al*., (2012), Mondal *et al*., (2014) and Khubele (2015) reported that the interaction effect of row width and maturity group had a significant effect on grain yield. Pederson and Lauer (2003) reported that narrow rows have a positive effect on grain yield. By contrast, Khubele (2015) reported that row width did not affect grain yield significantly.

4.5 Conclusion

The interaction effect of maturity group, plant density and row width significantly influenced all parameters measured, except for the number of days to 50% flower initiation, physiological maturity and the number of seeds per pod. The main effects had a significant effect on each parameter measured, except, with regard to the number of seeds per pod.

Maturity group emerged as the treatment factor that significantly affected phenological development i.e. number of days to 50% flower initiation (R1), flower initiation to inception seed-filling (R1-R5), inception of seed-filling to physiological maturity (R5-R8) and the total growth period. MG 4.5 reached R1 and R8 in the shortest number of days for both cropping seasons, followed by MG 5 and MG 6. This is due to the varietal characteristics of each maturity group, which are controlled by the specific maturity group's genetics and each response to photo period. Generally, plant height increased significantly with increasing plant density, with additional significant differences between maturity groups. The difference in plant height for the different maturity groups is also due to the varietal characteristic of each maturity group. Row width had a significant effect on plant height, but not profoundly so. Pod clearance was significantly affected by maturity group, with the highest pod clearance recorded for MG 6, followed by MG 5 and MG 4.5, with markedly significant differences between all three maturity groups for both cropping seasons. Plant density also affected pod clearance significantly for both cropping seasons, but with no definite trend. Row width had a significant effect only on pod clearance during the 2017/18 season, with 0.78 m rows recording a significantly higher pod clearance than the 0.38 m rows, although not to a profound level. Maturity group proved to have the greatest effect on plant and pod clearance, with plant density also affecting plant height greatly, while row width had a lesser impact on both plant and pod clearance. These results prove that soya beans show great plasticity regarding their adaptability to change or growth regulation in response to various agronomic factors.

Number of pods per plant was significantly affected by plant density, with number of pods per plant decreasing significantly with increasing plant density for both seasons. Maturity group also had a significant effect on the number of pods per plant, with MG 6 recording the greatest number of pods per plant for both seasons, followed by MG 5 and MG 4.5. Row width only had a significant effect on the interaction with plant density on the number of pods per plant during the 2017/18 season. Number of pods per plant was most greatly affected by plant density, with maturity group also having an effect. The row width effect was not as profound. Hundred-seed weight was significantly affected by row width for the 2016/17 season, with 0.78 m rows recording significantly the greatest hundred-seed weight. The 2017/18 season maturity group and plant density had a significant effect on hundred-seed weight with MG 4.5 recording the greatest hundred-seed weight, significantly greater than MG 6, followed by MG 5 with significantly the lowest hundred-seed weight. There were also significant differences between the different plant densities, with no definite trend. Hundred-seed weight was affected most acutely by maturity group, while plant density also produced an effect, with row width having a lesser effect.

Grain yield is the most important parameter measured because farmers are remunerated for yield (t ha^{-1}). Grain yield was influenced significantly by maturity group, plant density and row width. MG 6 recorded the greatest grain yield for both cropping seasons, followed by MG 4.5, and MG 5 for the 2016/17 season and MG 5 and MG 4.5 for the 2017/18 season. The North Eastern Free State's normal growing season dates from October, after the first sufficient and follow-up rainfall, to middle May, when the first frost normally occurs. The end of the growing season for both seasons was, on average, 30 April due to drought at the end of the 2016/17 season, and frost at the end of the 2017/18 season. Thus, both seasons had on average a growing period of 181 days (from 1 November to 30 April). Because both planting dates were relatively early/normal, 28 October 2016 and 7 November 2017, it was expected that the longer maturity group would record the greatest yield. This is due to the fact that MG 6 could utilize the growing season optimally.

Grain yield generally increased with a corresponding increase in plant density, but there was no definite trend. While there were significant differences obtained between plant densities, seed cost must be taken into consideration. For both seasons, satisfactory yields were obtained at 200 000 and 270 000 plants ha^{-1}, keeping in mind that the average plant density in the region ranges between 250 000 and 350 000 plants ha^{-1}. Thus, the slight increase in yield obtained by 400 000 plants ha^{-1} with the higher seed cost is not economically worthwhile. There was also a significant difference in grain yield in terms of the row width, only for the 2017/18 cropping season. However, in both seasons, the 0.38 m rows recorded the greater grain yield compared to the 0.76 m rows.

In conclusion it was determined that maturity group affected all parameters measured, with plant height, pod clearance and hundred-seed weight affected to the greatest extent. Plant density had the greatest effect on number of pods per plant, while also affecting plant height. Both maturity group and plant density affected grain yield, while row width also affected grain yield.

Chapter 5

The influence of maturity group, plant density, row width and planting date on the growth, yield components and yield of soya beans (*Glycine max* L.) in the North Eastern Free State between Frankfort and Jim Fouché

5.1 Introduction

As discussed in the previous chapters, a variety of uncontrollable and controllable factors exert an influence on soya bean production. Some of the controllable factors such as maturity group, plant density and row width and the significant effect which those have on soya bean production is already discussed. One factor that can be seen as an uncontrollable factor is planting date. However, if conditions are favourable, planting date can be controllable. Planting date is the single most influential factor affecting maturity group's yield (Vonk, 2013) and its response to plant density and row width. Because soya beans have different maturity groups, and are sensitive to photoperiod and temperature, plant density will affect each maturity group differently (Osman, 2011).

Planting date is influenced firstly by the first sufficient and follow-up rainfall as well as the minimum temperature required for emergence, and secondly, by the occurrence of frost early in the season. Planting date is also influenced by other farm practices, such as other crops that are planted first or uncontrollable factors which influence the planting date occurring earlier or later in the season. Planting date thus influences the growing season length, while in effect affecting the response of each maturity group (Heatherly, 1999; Pedersen and Lauer, 2004; Egli and Cornelius, 2009; Robinson *et al*., 2009).

In the North Eastern Free State, the normal (considered as early in this study) planting date is considered as from 15 October till 15 November, and late planting date is estimated as after 15 November till December. Planting dates after 15 December are not recommended in the North Eastern Free State. Research done on the effect of planting date on soya bean production showed that delayed planting dates resulted in significant yield reduction in all maturity groups (Pedersen and Lauer, 2004, Salmerón *et al*., 2015). According to Salmerón *et al*., (2015), the yield reduction is due to a shortened growing season, less optimum temperatures, and a reduction in sunlight. Later planting dates also result in shorter vegetative and reproductive stages, resulting in smaller plants (Chen and Wiatrak, 2010). Because each maturity group responds differently to different planting dates, Salmerón *et al*., (2015) found that early maturity groups, such as MG 4 produced similar yields at different planting dates, because of a shorter growing season length needed to complete growth, and production to produce optimal yields, while longer growing maturity groups such as MG 5 and MG 6, which require a longer growing season to complete growth and development, produced lower yields at late planting dates. This was due to the growing season being shorter than the period required to produce optimal yields. According to various studies, shorter growing maturity groups have a greater probability of achieving greater yields at late planting dates compared to longer growing maturity groups. Longer growing maturity groups have the greatest probability of achieving higher yields compared to shorter growing maturity groups (Heatherly, 1999; De Bruin and Pedersen, 2008a; Robinson *et al*., 2009; Chen and Wiatrak, 2010; Salmerón *et al*., 2015).

Maturity is not the only factor influenced by planting date. However, it is the factor which is most influenced by plant density. Planting date also influences the response of soya beans to plant density and row width. In research done on the effect of planting date on the response of soya bean on plant density Ball *et al*., (2001) reported that, at early planting dates, low planting dates produced adequate pods per plant for satisfactory yields compared to higher plant densities. The reason for this is more vegetative growth, more fertile nodes, and more pod production to compensate for lower plant densities. However, at later planting dates more plants per hectare were necessary to produce the same number of pods per plant and yields. In a study done by Boquet (1990), results showed that at late planting dates, narrow rows partially compensated for reduced yield. Because delayed planting resulted in smaller plants due to a shortened growing season, soya bean plant responds to higher plant densities and narrower row widths to compensate for reduced yields.

Considering the studies that were done over a wide range of conditions, and knowing that planting date influences the response of maturity group, plant density and row width on yield, it is critical to choose the correct maturity group and the correct combination of plant density and row width for each maturity group at different planting dates. The objective was to evaluate the effect of early/normal and late planting dates on different maturity groups at different plant densities, and row widths in the North Eastern Free State on yield.

5.2 Materials and Methods

5.2.1 Experimental site

Two field experiments were conducted during the 2016/17 and 2017/18 cropping seasons with two planting dates within each season on a farmer's field located in the North Eastern Free State between Frankfort and Jim Fouché. Geographically, the experimental site is situated at 1 554 m above sea level on latitude -27.127268 and longitude 28.456078. Rainfall data measured with a rain gauge on the experimental sites during the two growing seasons are summarized in Table 5.1. The chemical and physical soil properties are summarized in Table 5.2.

Table 5.1 Rainfall (mm) for the 2016/17 and 2017/18 cropping seasons at the experimental sites between Frankfort and Jim Fouché

	Rainfall (mm)									
Season	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
2016/17	11	61	142	144	156	222	41	13	11	**804**
2017/18	5	48	97	140	84	76	154	23	27	**654**

Table 5.2 Chemical and physical soil properties of the experimental sites between Frankfort and Jim Fouché

Physical properties	**Cropping season**	
	2016/17	**2017/18**
Clay (%)	6	8
Density ($g.cm^{-3}$)	1.17	1.25
Chemical properties		
pH (KCl)	4.8	4.7
Nutrients ($mg\ kg^{-1}$)		
P (Bray 1)	161.2	46.3
K (NH_4OAc)	146.7	110.3
Ca (NH_4OAc)	274	45
Mg (NH_4OAc)	38.4	14.6
Na (NH_4OAc)	5	1
S (NH_4OAc)	9.91	32.82
Exchangeable acids	0	1.12
Acid saturation (%)	0	1.21
Ca/Mg	4.35	1.88
(Ca+Mg)/K	4.49	1.22
CEC (cmolc kg^{-1})	2.08	1.75

* Soil sample taken at a depth of 0-20 cm

5.2.2 Experimental Design and Treatments

The experimental design was a factorial experiment laid out in a split-split plot design with four replications. Treatments included three cultivars (maturity groups), four plant densities and two row widths planted at two planting dates. The first planting date is considered to be an early/normal and optimum planting date for the North Eastern Free State, while the second planting date is considered as a late and less optimum planting date. The main plot factor was maturity groups (MG), with plant density (PD) the sub-plot factor and row width (RW) viewed as the sub-sub plot factor. The three cultivars used in this experiment was SSS 4945 tuc (MG 4.5), SSS 5449 tuc (MG 5) and SSS 6560 tuc (MG 6). MG 4.5 is classified as a short, MG 5 as a medium and MG 6 as a medium-long maturity group. Other cultivar characteristics are summarized in Table 5.3. The four plant densities represented a plant stand of 150 000, 300 000, 400 000 and 600 000 plants ha^{-1} and the two row widths were 0.30 m and 0.60 m.

Each plot consisted of 16 sub-plots and 32 sub-sub plots. Each sub-sub plot was 5 m long with 1 m paths between plots, consisting of four planting rows for the 0.60 m row width and eight planting rows for the 0.30 m row widths. The planting rows were spaced 0.60 m (with 4 plant rows) or 0.30 m (with 8 plant rows) apart, making one sub-plot 4.8 m and one sub-sub plot 2.4 m wide. In total there were 3 main plots with 48 sub-plots and 96 sub-sub plots. Each main plot measured 98 m x 4.8 m, each sub-plot 5 m x 4.8 m, and each sub-sub plot 5 x 2.4 m. Finally, the total area designated for the experiment measured 1411.2 m^2 (98 m x 14.4 m).

Table 5.3 Cultivar characteristics representing the three (3) maturity groups (MG)

Characteristic	**Cultivar**		
	SSS 4945 tuc	**SSS 5449 tuc**	**SSS 6560 tuc**
Maturity Group	4.5	5	6
Growth Type	Semi-indeterminate	Indeterminate	Indeterminate
Growth Period	Short	Medium	Medium to long
Days to flowering	59	63	70
Days to harvest (moderate – cooler areas)	133 – 144	139 - 157	155 - 171
Plant Height (cm)	65	90	90
Pod clearance (1=high, 9=low)	5	2	2
Standability	Excellent	Good	Good
Shattering resistance	Resistant	Good	Good
Seed Density (Plants/ha^{-1})			
Dryland- Cooler	320 000 - 360 000	300 000 - 340 000	280 000 - 300 000
Dryland- Warmer	380 000	340 000	320 000
Row width/ Thousand seeds ('000)	76 cm 52 cm 38 cm 320 340 360	76 cm 52 cm 38 cm 300 320 340	91 cm 76 cm 52 cm 38 cm 280 280 300 300

5.2.3 Agronomic practices and management of the experimental site

The experiments were conducted under dry land conditions over two cropping seasons (2016/17 and 2017/18) at two different locations on the farm. The preceding crop for both season's experimental sites was maize (*Zea mays* L.) and the tillage system was rip and disc before plant. The first planting date was 28 October 2016 and second planting date was 5 December 2016 for the 2016/17 cropping season. For the 2017/18 cropping season, the first planting date was 16 November 2017 and the second planting date was 4 December 2017. The planting process was done with a 14-row planter suited for planting soya beans at variable/different planting densities by adjusting planting gears. The planter units were spaced 0.60 m apart. To realize 0.30 m rows the 0.60 m set planter was used to plant in-between existing rows. Each maturity group consisted of eight (8) rows for the 0.30 m row width and four (4) rows for the 0.60 m row width. Only the middle two and middle four rows were used to collect data for the 0.60 and 0.30 m rows, respectively. Desired planting densities were obtained by adjusting the planter's gears. The experimental site was fertilized according to best agronomic practices. Fertilizer was broadcast before planting with a compound fertilizer 1:1:2(20) at 200 kg ha^{-1}. Seeds were inoculated with a *Bradyrhizobium japonicum* inoculant before planting. Weeds were sprayed with Roundup PowerMax at a rate of 1.5 L ha^{-1} (540 g a.i. L^{-1}) six (6) weeks after planting.

At harvest, each sub-sub plot was manually harvested, pulling each plant manually and transported from the field in poly propylene bags. Plants were threshed mechanically, moisture content was determined, and yields adjusted to a 12.5% moisture content.

5.3 Data Collection and Measurements

5.3.1 Phenological development and Growth parameters

a. Phenological development: Number of days from plant to 50% flower initiation (Plant-R1), flower initiation to inception seed-filling (R1-R5), inception seed-filling to physiological maturity (R5-R8) and total growth period (Plant-R8).

b. Days to 50% flower initiation: Days to flower initiation (R1 – when 50% of all plants have an open flower at one of the two uppermost nodes on the main stem with a fully developed leaf) was recorded as the number of days from plant up until the R1 stage for each sub-sub plot.

c. Reproductive growth stage: The stage of reproductive growth was recorded each week from flower initiation (R1) up until physiological maturity (R8) for each sub-sub plot.

d. Plant height (cm): Plant height of three plants for each sub-sub plot was measured on a weekly basis up until physiological maturity. Plant height was measured from the soil surface to the highest natural growth point of plants. Only the final plant height will be discussed.

e. Pod clearance (cm): Pod clearance of three plants for each sub-sub plot was measured before harvesting after physiological maturity. Measurements were taken from the soil surface to the lowest point of the natural hanging pod.

5.3.2 Yield and yield components

a. Number of pods per plant: For each sub-sub plot a total of ten plants' pods were sampled and counted after harvest.

b. Number of seeds per pod: Number of seeds per plant was counted and divided by the number of pods to determine the number of seeds per pod.

c. Hundred-seed weight: A hundred-seeds were counted from the harvested grain and weighed. The weight was adjusted to a moisture content of 12.5%.

d. Grain yield: Grain yield for each sub-sub plot was harvested and converted to ton per hectare and its moisture content was adjusted to 12.5%.

5.3.3 Statistical analysis

Data was analysed using the statistical program SAS version 9.2® (SAS Inst., 1992). Treatment means were separated using Tukey's least significance difference (LSD) test at a 5% level of confidence. Planting date was not statistically analysed and will only be compared during discussions.

5.4 Results and Discussion

Analysis of variance indicated that data from the 2016/17 and 2017/18 cropping seasons were not homogeneous, most probably as a result of climatic differences. Therefore, the two cropping seasons will be discussed separately, whereafter the comparison between the two planting dates will be discussed.

A summary of the analysis of variance evaluating the effect of maturity group, plant density and row width on soya bean plants for both planting dates is given in Table 5.4 and Table 5.5. Only maturity group affected the number of days to a specific development stage (plant to R1, R1 to R5 and R5 to R8) significantly. The treatment factors had no significant effect on the number of seeds per pod. Plant height, pod clearance, hundred-seed weight and grain yield were significantly affected by maturity group for both seasons and planting dates, except for hundred-seed weight during the 2017/18 season's second planting date. Maturity group also affected the number of pods per plant during the second planting date. Plant density affected plant height, pod clearance and number of pods per plant for both plantings and seasons as well as the hundred-seed weight of the 2016/17 cropping season significantly. Grain yield was only significantly affected by plant density during the second planting of both seasons. Row width affected only plant height for both plantings, and both cropping seasons. The MG by PD interaction proved to be significant for both seasons and plantings on account of pod clearance, number of pods per plant and grain yield. Similarly, MG by RW was significant for pod clearance and grain yield only. On account of the PD by RW interaction, none of the plant parameters were significantly affected for both plantings and both cropping seasons. Although significant three-way interactions (MG X PD X RW) were observed, only two-way interactions will be discussed.

Table 5.4 Summary of analysis of variance indicating the effect of treatment factors on measured plant parameters for the 2016/17 season

Treatments	Days to specific development stage								Growth parameters				Yield and yield components							
	Plant-R1		R1-R5		R5-R8		Total growth period		Plant height		Pod clearance		Number of pods per plant		Number of seeds per pod		Hundred-seed weight		Grain yield	
Planting date	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Maturity group (MG)	*	*	*	*	*	*	*	*	ns	*	*	*	ns	*	ns	ns	*	*	*	*
Plant density (PD)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	*	ns	ns	*	*	ns	*
Row width (RW)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	*	ns	ns	ns	*	*	*
MG X PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	ns	ns	*	*	*	*
MG X RW	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	*	ns	ns	*	*	*	*
PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	ns	ns	*	*	*	*
MG X PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns	*	ns	*
CV %	0.99	0.80	1.82	1.83	1.62	1.45	0.48	0.28	5.84	3.87	14.87	17.40	24.36	6.92	5.07	5.39	20.66	26.51	12.94	21.20

Table 5.5 Summary of analysis of variance indicating the effect of treatment factors on measured plant parameters for the 2017/18 season

Treatments	Days to specific development stage								Growth parameters				Yield and yield components							
	Plant-R1		R1-R5		R5-R8		Total growth period		Plant height		Pod clearance		Number of pods per plant		Number of seeds per pod		Hundred-seed weight		Grain yield	
Planting date	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Maturity group (MG)	*	*	*	*	*	*	*	*	*	*	*	*	ns	*	ns	ns	*	ns	*	*
Plant density (PD)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	*	ns	ns	*	ns	ns	*
Row width (RW)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	*	ns	*	ns	ns	ns	ns	ns	*
MG X PD	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	*	*	ns	ns	*	ns	*	*
MG X RW	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	ns	*	ns	ns	*	ns	*	*
PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	*	*	ns	ns	*	ns	ns	*
MG X PD X RW	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	ns	*	ns	ns	ns	ns	ns	*
CV %	1.18	1.01	1.55	1.62	1.73	1.79	0.62	0.45	2.31	3.29	4.88	4.49	23.53	13.47	4.90	4.46	21.48	4.57	11.77	12.02

ns – not significant
*** - P ≤ 0.05**
CV – coefficient of variance

5.4.1 Phenological development

The number of days from plant to 50% flower initiation (Plant-R1), flower initiation to beginning seed-filling (R1-R5), beginning of seed-filling to physiological maturity (R5-R8) and total growth period will be discussed.

5.4.1.1 2016/17

Analysis of variance indicated that maturity group was the only factor that influenced the number of days for each of the developing stages *viz*. plant-R1, R1-R5 and R5-R8, and total growth period had a significant influence on both planting dates (Table 5.4).

For the first planting between all three maturity groups, highly significant differences occurred regarding the number of days to R1 (Table 5.6). The number of days required to reach R1 for MG 4.5 was only 49 days, while MG 5 took 56 days and MG 6 70 days. This was considerably quicker for MG 4.5 (10 days) and MG 5 (7 days) while MG 6 concurs with the average recommendation for each cultivar reaching R1 (Table 5.3). The number of days from R1 to R5 also produced highly significant differences, with MG 4.5 and MG 6 both taking 28 days from R1 to R5, significantly less than MG 5, which took 35 days. MG 5 took 49 days to progress from R5 to R8, significantly less than MG 4.5 and MG 6 which both took 56 days. To reach physiological maturity, MG 4.5 took the least number of days, *viz*. 133 days, followed by MG 5, taking significantly more with 140 days and MG 6 with significantly the greatest number of days *viz*. 154 days. For all three maturity groups the number of days to taken reach physiological maturity concurs with the average recommendation for each cultivar, taking into consideration the dry-off period of 7 to 10 days, and depending on weather conditions, which is needed to be added to the total growth period before harvest could commence (Table 5.3).

For the second planting the number of days to R1 MG 4.5 and MG 5 took only 42 days, while MG 6 took significantly longer with 56 days (Table 5.6). The number of days to reach R1 for each maturity group was considerably less than the average recommendation for each cultivar (Table 5.3). In terms of speed, MG 4.5 was 17 days quicker, MG 5 21 days and MG 6 14 days. The number of days from R1 to R5 also produced highly significant differences, with MG 4.5 only taking 21 days from R1 to R5, significantly less than MG 6 which took 35 days and MG 5, 42 days. The number of days from R5 to R8 took MG 5 28 days, significantly less than MG 6 which took 42 days and MG 4.5 which took 49 days. MG 4.5 and MG 5 took the least number of days to reach physiological maturity with 112 days. MG 6 took significantly more time, with

133 days to reach physiological maturity. These results (days to harvest) were also considerably more rapid than the average recommendation for each cultivar. MG 4.5 was 21 days quicker, MG 5 27 days and MG 6 22 days more rapid (Table 5.3).

Table 5.6 Effect of maturity group on the number of days to flower initiation (R1), flower initiation to seed-fill (R1-R5), seed-fill to physiological maturity (R5-R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant - R1**	**R1 - R5**	**R5 - R8**	
First planting				
4.5	49	28	56	133
5	56	35	49	140
6	70	28	56	154
MG $_{LSD\ (0.05)}$	1.00	0.96	1.50	1.19
Second planting				
4.5	42	21	49	112
5	42	42	28	112
6	56	35	42	133
MG $_{LSD\ (\leq 0.05)}$	0.64	1.04	1.00	0.58

5.4.1.2 2017/18

Similar to the 2016/17 cropping season, maturity group was once more the sole factor that influenced the number of days required for each of the developing stages *viz*. plant-R1, R1-R5 and R5-R8 significantly, according to the analysis of variance for both planting dates (Table 5.5).

For the first planting the number of days taken to reach R1 for MG 4.5 was only 49 days, while both MG 5 and MG 6 took 77 days (Table 5.7). Between MG 4.5 and both MG 5 and MG 6 there were highly significant differences for the number of days to R1. This was considerably quicker for MG 4.5 and longer for both MG 5 and MG 6 than the average recommendation for each cultivar to reach R1 (Table 5.3). The number of days from R1 to R5 also produced highly significant differences, with MG 5 and MG 6 both taking 35 days, from R1 to R5, significantly less than MG 4.5 which took 42 days. The number of days from R5 to R8 took MG 5 35 days, significantly less than MG 4.5 and MG 6 which both took 42 days. MG 4.5 took the least number of days to reach physiological maturity with 133 days, followed by MG 5 taking significantly more, with 147 days, and MG 6 with significantly the greatest number of days with 154 days to reach physiological maturity. For all three maturity groups the number of days taken to reach physiological maturity concurs with the average recommendation for each cultivar (Table 5.3).

For the second planting, the number of days for MG 4.5 to reach R1 took only 42 days, while MG 5 and MG 6, respectively took 56 and 63 days (Table 5.7). Between MG 4.5, MG 5, and MG 6 there were highly significant differences for the number of days to R1. The number of days taken to reach R1 for each MG was considerably less than the average recommendation for each cultivar (Table 5.3). MG 4.5 was 17 days quicker, while both MG 5 and MG 6 were 7 days quicker. The number of days from R1 to R5 also produced highly significant differences, with MG 4.5 and MG 6 which both took 35 days, significantly less than that of MG 5 (42 days). The number of days from R5 to R8 took both MG 4.5 and MG 5 35 days, significantly less than MG 6 which took 42 days. MG 4.5 took the least number of days to reach physiological maturity with 112 days, followed by MG 5 which took significantly more, with 133 days, and MG 6 with significantly the greatest number of days *viz*. 140 days to reach physiological maturity. These results (days to harvest) were also considerably more rapid than the average recommendation for each cultivar. MG 4.5 was 21 days quicker, MG 5 6 days and MG 6 15 days (Table 5.3).

Table 5.7 Effect of maturity group on the number of days to flower initiation (R1), flower initiation to seed-fill (R1-R5), seed-fill to physiological maturity (R5-R8) and total growth period

Treatment	**Number of days from:**			**Total growth period (days)**
Maturity group	**Plant - R1**	**R1 - R5**	**R5 - R8**	
First planting				
4.5	49	42	42	133
5	77	35	35	147
6	77	35	42	154
MG LSD $_{(0.05)}$	1.38	1.00	1.19	1.55
Second planting				
4.5	42	35	35	112
5	56	42	35	133
6	63	35	42	140
MG $_{LSD\ (\leq 0.05)}$	0.96	1.04	1.15	1.00

For the 2016/17 season there were differences in the number of days taken to reach a specific development stage and total growth period between the two planting dates. The number of days taken from plant to R1 was 7 days longer for MG 4.5 and 14 days longer for MG 5 and MG 6 for the first planting compared to the second planting. However, the number of days from R1 to R5 was also 7 days longer for MG 4.5 for the first planting, while for MG 5 and MG 6, the same time span was 7 days shorter for the first planting compared to the second planting. The number of days from R5 to R8 was 7 days longer for MG 4.5, 21 days longer for MG 5 and 14 days longer for MG 6 for the first planting compared to the second planting. The total growth period for the first planting was 21 days longer for MG 4.5 and MG 6, while 28 days longer for MG 5.

For the 2017/18 season there were differences in the number of days taken to reach a specific development stage and total growth period between the two planting dates. The number of days from plant to R1 was 7 days longer for MG 4.5, 21 days longer for MG 5 and 14 days longer for MG 6 for the first planting compared to the second planting. The number of days from R1 to R5 was also 7 days longer for MG 4.5 for the first planting, while for MG 5, the time taken was 7 days shorter for the first planting compared to the second planting, and for MG 6 the same number of days were taken. The number of days from R5 to R8 was 7 days longer for MG 4.5, while the same for MG 5 and MG 6 for the first planting compared to the second planting. The total growth period for the first planting was 21 days longer for MG 4.5, while 14 days longer for MG 5 and MG 6.

For the 2016/17 season the number of days taken to reach each development stage and total growth period was considerably longer for the first planting compared to the second planting. For the 2017/18 season the result was similar. However, for MG 5 and MG 6 the number of days from R5 to R8 was the same for both planting dates, and the difference in total growth period between the two planting dates was slighter compared to the 2016/17 season. This result is in agreement with Chen and Wiatrak (2010), who reported that a late planting date can reduce the total length of the vegetative period, flowering, pod-set, and to a lesser extent, seed-fill period.

Because the second planting date had, in effect, a shorter growing season, it was expected that the number of days for each development stage and the total growth period would be shorter compared to the first plating date. However, MG 5 and MG 6, during the 2016/17 season, and MG 5 during the 2017/18 season, had a longer period from R1 to R5 during the second planting date. For the 2017/18 season, the number of days from R5 to R8 for MG 5 and MG 6 was the same. The reason for this could possibly be a response of the soya bean plant to producing more flowers for a longer duration. This would indicate an enhancement of the plant’s capacity for adoptive change, producing more pods per plant and increasing the seed-filling period in an attempt to produce a maximum yield. This further proves of the soya bean plant’s ability to compensate, and further indicates it’s the variability and adaptability due to different growing conditions (temperature and photoperiod-planting date).

The reason for the significant differences in the number of days taken to undergo specific development stages between maturity groups might be due to the fact that the vegetative and reproductive stage in soya beans are a varietal characteristic, and that soya bean varieties react differently to day length, which is controlled by the specific maturity group's genetic make-up (Fehr and Caviness, 1977; Boquet 1998; Han *et al*., 2006) According to seed company's indications for each maturity group, there are significant differences in the number of days taken to reach flower initiation and physiological maturity, confirming the result obtained.

This study's results are similar to the findings in Chapter 3 and 4 (See Chapter 3.4.1.2 for discussion). In agreement with the factor of planting date examined in this study, Kumagai and Takahashi (2020) reported that planting dates have a significant effect on each development stage of soya beans. They reported that a delay in planting date by four weeks resulted in a shorter period from plant to full bloom (R2) from 53 to 41 days. The total growth period was also shortened from 121 to 108 days. Hu (2013) also reported that a four-week delay in planting resulted in a 10% shorter reproductive period, and a shorter period to flowering by 14% and 27% (1.9 and 3.9 days), respectively for two different maturity groups *viz*. MG 7 and MG 8. The pod-set period was also shortened by 20 and 29% (3 and 3.5 days), while the seed-fill period was shortened by 7% (3 days) for both maturity groups.

5.4.2 Plant height

5.4.2.1 2016/17

Plant height at physiological maturity was significantly affected by the main effects of plant density and row width as well as the interaction effects of MG by PD, MG by RW and PD by RW for both planting dates, while maturity as main effects also affected plant height for the second planting date (Table 5.4).

For the first planting, plant height increased with each increment in plant density from 150 000 plants ha^{-1} (76.92 cm) to 300 000 plants ha^{-1} (83.08 cm) whereafter plant height increased significantly to 400 000 plants ha^{-1} (93.71 cm) as well as 600 000 plants ha^{-1} (101.04 cm) (Table 5.8). Row width had a highly significant effect on plant height with 0.60 m rows recording the highest plant height (91.79 cm) compared to that of 0.30 m rows (85.58 cm) (Table 5.9).

For the second planting, maturity group significantly affected plant height with MG 6 recording significantly the highest plant height (60.84 cm), followed by MG 5 (57.63 cm) and MG 4.5 (56.41 cm) with no significant difference between the latter two (Table 5.8). Plant height increased significantly with increasing plant density from 150 000 plants ha^{-1} (46.58 cm) to 300 000 plants ha^{-1} (53.50 cm), as well as up to 400 000 plants ha^{-1} (61.13 cm) and 600 000 plants ha^{-1} (71.96 cm) (Table 5.9). Row width had a significant effect on plant height with the 0.60 m rows recording the significantly highest plant height (62.79 cm) compared to 0.30 m rows (56.41 cm) (Table 5.9).

Plant height for the first and second planting was significantly affected by the MG by PD interaction (Table 5.8). For the first planting, between maturity groups within each plant density increment there were no significant differences in plant height, except between MG 4.5 and MG 5 at 400 000 plants ha^{-1}. Plant height increased with each increment plant density for all three maturity groups. For the second planting between all three maturity groups, generally the highest plant height was recorded at MG 6, followed by MG 5 and MG 4.5. There was generally no significant effect in plant height between all three maturity groups within each plant density. Within each plant density increment, the only significant difference in plant height between maturity groups was recorded only within 600 000 plants ha^{-1} between all three maturity groups, with MG 6 recording the highest plant height (77.75 cm), followed by MG 5 (71.75 cm) and 4.5 (66.38 cm). The greatest significance was recorded within each maturity group between each plant density increment. With each increment in plant density, plant height increased significantly. Similar to the first planting, plant density contributed the most to plant height being significantly affected by the MG by PD interaction.

Plant height for the first and second planting was significantly affected by the MG by RW interaction (Table 5.9). For the first planting, 0.60 m rows recorded significantly higher plant heights for both MG 5 and 6. Within each row width there were no significant differences in plant height between all three maturity groups. For the second planting 0.60 m rows recorded significantly higher plant heights for both MG 4.5 and 5, while MG 6 also recorded a higher plant height at 0.60 m rows, but not significantly so. Within the 0.60 m rows there was a significant difference in plant height between MG 4.5 (61.25 cm) and MG 5 (64.94) only. Within the 0.30 m rows, MG 6 recorded a significant highest plant height (59.50 cm), followed by MG 4.5 (51.56 cm) and MG 5 (50.31 cm), with no significant difference between the latter two. There were no significant differences in plant height within the 0.60 m rows. Similar to the first planting, row width contributed the most to plant height which was significantly affected by the MG by RW interaction.

Table 5.8 Effect of maturity group and plant density on plant height (cm)

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	76.88	75.38	78.50	76.92
300 000	83.25	84.63	81.38	83.08
400 000	88.88	98.00	94.25	93.71
600 000	98.00	102.88	102.25	101.04
Mean	86.75	90.22	89.09	
Second planting				
150 000	45.63	45.75	48.38	46.58
300 000	54.25	52.00	54.25	53.50
400 000	59.38	61.00	63.00	61.13
600 000	66.38	71.75	77.75	71.96
Mean	56.41	57.63	60.84	

First planting
MG $_{LSD\ (\leq 0.05)}$ = ns
PD $_{LSD\ (\leq 0.05)}$ = 6.38
MG x PD $_{LSD\ (\leq 0.05)}$ = 8.91

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 1.82
PD $_{LSD\ (\leq 0.05)}$ = 2.25
MG x PD $_{LSD\ (\leq 0.05)}$ = 3.89

Table 5.9 Effect of maturity group and row width on plant height (cm)

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	85.31	86.44	85.00	85.58
0.60 m	88.19	94.00	93.19	91.79
Mean	86.75	90.22	89.09	
Second planting				
0.30 m	51.56	50.31	59.50	53.79
0.60 m	61.25	64.94	62.19	62.79
Mean	56.41	57.63	60.84	

First planting
MG $_{LSD\ (\leq 0.05)}$ = ns
RW $_{LSD\ (\leq 0.05)}$ = 2.50
MG x RW $_{LSD\ (\leq 0.05)}$ = 6.55

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 1.82
RW $_{LSD\ (\leq 0.05)}$ = 1.22
MG x RW $_{LSD\ (\leq 0.05)}$ = 3.20

Plant height for the first and second planting was significantly affected by the PD by RW interaction (Table 5.10). For the first planting 0.60 m rows recorded a significant highest plant height only at 400 000 and 600 000 plants ha^{-1} compared to 0.30 m rows. Within each row width, plant height generally increased significantly with each increment increase in plant density. For the second planting between row widths, the 0.60 m rows recorded the significant highest plant height compared to 0.30 m rows at all plant density increments, except at 600 000 plants ha^{-1}. Within each row width, plant height increased significantly with each increment increase in plant density. Similar to the first planting, both plant density and row width contributed equally the effect of this interaction on plant height.

Table 5.10 Effect of plant density and row width on plant height (cm)

Plant density (plants ha^{-1})	**Row width**		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	75.00	78.83	76.92
300 000	80.67	85.50	83.08
400 000	89.33	98.08	93.71
600 000	97.33	104.75	101.04
Mean	85.58	91.79	
Second planting			
150 000	39.33	53.83	46.58
300 000	47.25	59.75	53.50
400 000	56.92	65.33	61.13
600 000	71.67	72.25	71.96
Mean	53.79	62.79	

First planting
PD $_{LSD\ (\leq 0.05)}$ = 6.38
RW $_{LSD\ (\leq 0.05)}$ = 2.50
PD x RW $_{LSD\ (\leq 0.05)}$ = 6.71

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 2.25
RW $_{LSD\ (\leq 0.05)}$ = 1.22
PD x RW $_{LSD\ (\leq 0.05)}$ = 2.93

5.4.2.2 2017/18

Plant height at physiological maturity was significantly affected by the main effects of maturity group, plant density and row width as well as the interaction effect of MG by PD, MG by RW and PD by RW for both the first and second planting date (Table 5.5).

For the first planting date, MG 6 recorded the significantly highest plant height (81.66 cm), followed by MG 5 (75.75 cm) and MG 4.5 (57.03 cm) (Table 5.11) with significant difference between all three maturity groups. Plant height surprisingly decreased significantly with each incremental increasing in plant density (Table 5.11). This result is the opposite to that of the previous cropping season, as well as the results discussed in the previous chapters. Plant height decreased significantly from 150 000 plants ha^{-1} (76.46 cm) to 300 000 plants ha^{-1} (71.08 cm) whereafter it decreased to 400 000 plants ha^{-1} (70.33 cm) and again decreased significantly to 600 000 plants ha^{-1} (68.04 cm). Row width also had a highly significant effect on the plant height with the 0.60 m rows recording 75.69 cm, followed by 0.30 m rows recording a plant height of 67.27 cm. (Table 5.12).

For the second planting date, MG 6 recorded the significantly highest plant height (75.00 cm), followed by MG 5 (71.75 cm) and MG 4.5 (59.72 cm) with significant difference between all three maturity groups (Table 5.11). Plant height generally increased with increasing plant density. Plant height increased from 150 000 plants ha^{-1} (65.42 cm) to 300 000 plants ha^{-1} (68.75 cm), as well as to 400 000 plants ha^{-1} (70.63 cm) and slightly decreased to 600 000 plants ha^{-1} (70.50 cm) (Table 5.11). The only significant difference was recorded between 150 000 plants ha^{-1} and both 400 000 plants ha^{-1} and 600 000 plants ha^{-1}. Row width had a significant effect on plant height, with the 0.60 m rows recording the significantly highest plant height (70.90 cm), followed by that of the 0.30 m rows (66.75 cm) (Table 5.12).

Plant height for the first and second planting was significantly affected by the MG by PD interaction (Table 5.11). For the first planting, plant height surprisingly decreased with each increment in plant density for all three maturity groups. The only significant difference within each maturity group was recorded at MG 6 between 150 000 plants ha^{-1} (87.50 cm) and 600 000 plants ha^{-1} (75.63 cm). Between maturity groups and within each plant density increment both MG 5 and MG 6 recorded significantly higher plant heights than those of MG 4.5. MG 6 recorded the highest plant height for each plant density increment, higher than that of MG 5 and significantly higher than that of MG 4.5. For the second planting, plant height generally increased with each increment in plant density for all three maturity groups with the only significant differences recorded within MG 4.5 and 5. Within each plant density increment, MG 6 recorded the highest plant height, followed by MG 5 and MG 4.5. Both MG 5 and MG 6 at each plant density increment recorded a significantly higher plant height than that of MG 4.5, with the only significant difference occurring between MG 5 and MG 6 at 150 000 plants ha^{-1}. Similar to the first planting, maturity group contributed most to plant height being significantly affected by this interaction.

Plant height for the first and second planting was significantly affected by the MG by RW interaction (Table 5.12). For the first planting, 0.60 m rows recorded higher plant heights than those of 0.30 m rows and significantly greater heights at MG 4.5 and MG 5. Between maturity groups and within each row width, plant height increased significantly from MG 4.5 to MG 5, while MG 6 recorded the highest plant heights. For the second planting, 0.60 m rows recorded a significantly higher plant height than that of 0.30 m rows for MG 5 and 6. Between maturity groups and within each row width, plant height increased significantly from MG 4.5 to MG 5, while MG 6 recorded the greatest plant height. Similar to the first planting maturity group and row width contributed equally to plant height being significantly affected by this interaction.

Plant height for the first and second planting was significantly affected by the PD by RW interaction (Table 5.13). For the first planting, 0.60 m rows recorded the significantly highest plant height compared to 0.30 m rows. Within each row width, surprisingly, plant height generally decreased with each increment increase in plant density. For the second planting, 0.60 m rows generally recorded the significant highest plant height compared to 0.30 m rows. Within each row width, plant height generally increased with each increment increase in plant density. Similar to the first planting, row width contributed more to plant height, the latter being significantly affected by this interaction.

Table 5.11 Effect of maturity group and plant density on plant height (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	62.50	79.38	87.50	76.46
300 000	55.63	75.25	82.38	71.08
400 000	55.00	74.88	81.13	70.33
600 000	55.00	73.50	75.63	68.04
Mean	57.03	75.75	81.66	
Second planting				
150 000	55.63	66.25	74.38	65.42
300 000	59.13	72.50	74.63	68.75
400 000	63.50	73.88	74.50	70.63
600 000	60.63	74.38	76.50	70.50
Mean	59.72	71.75	75.00	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 3.72
PD $_{LSD\ (\leq 0.05)}$ = 1.64
MG x PD $_{LSD\ (\leq 0.05)}$ = 8.91

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.19
PD $_{LSD\ (\leq 0.05)}$ = 3.49
MG x PD $_{LSD\ (\leq 0.05)}$ = 3.92

Table 5.12 Effect of maturity group and row width on plant height (cm)

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	51.56	71.56	78.69	67.27
0.60 m	62.50	79.94	84.63	75.69
Mean	57.03	75.75	81.66	
Second planting				
0.30 m	60.00	68.38	71.88	66.75
0.60 m	59.44	75.13	78.13	70.90
Mean	59.72	71.75	75.00	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 3.72
RW $_{LSD\ (\leq 0.05)}$ = 2.50
MG x RW $_{LSD\ (\leq 0.05)}$ = 6.55

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.19
RW $_{LSD\ (\leq 0.05)}$ = 1.48
MG x RW $_{LSD\ (\leq 0.05)}$ = 3.87

Table 5.13 Effect of row width and plant density on plant height (cm)

Plant density (plants ha^{-1})	Row width		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	72.92	80.00	76.46
300 000	67.25	74.92	71.08
400 000	65.58	75.08	70.33
600 000	63.33	72.75	68.04
Mean	67.27	75.69	
Second planting			
150 000	64.58	66.25	65.42
300 000	67.08	70.42	68.75
400 000	67.50	73.75	70.63
600 000	67.83	73.17	70.50
Mean	66.75	70.90	

First planting
PD $_{LSD\ (\leq 0.05)}$ = 1.64
RW $_{LSD\ (\leq 0.05)}$ = 2.50
RW x PD $_{LSD\ (\leq 0.05)}$ = 6.71

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 3.49
RW $_{LSD\ (\leq 0.05)}$ = 1.48
PD x RW $_{LSD\ (\leq 0.05)}$ = 2.95

For the 2016/17 season, plant height was similarly affected by plant density and row width between both planting dates. For both planting dates, plant height generally increased significantly with each increment in plant density, while 0.60 m rows recorded a significantly higher plant height compared to 0.30 m rows. The trend in which plant density and row width affected plant height was similar. However, the plant height recorded for the first planting date was considerably higher (± 30 cm/42 to 65%) compared to the second planting date. While all three factors, maturity group, plant density and row width, as well as the interaction effects significantly affected plant height, plant density and row width had the greatest effect on plant height, while the effect of maturity group was not as profound.

For the 2017/18 season, plant height was affected similarly by maturity group and row width between both planting dates, while plant density affected plant height differently between planting dates. For both planting dates, MG 6 recorded the highest plant height, followed by MG 5. MG 4.5 recorded by far the lowest plant height. 0.60 m rows recorded the significantly highest plant heights compared to 0.30 m rows for both planting dates. Plant height surprisingly decreased with increased plant density for the first planting, while as suspected, increased with increased plant density for the second planting. Although maturity group and row width affected plant height for both planting dates following the same trend, while plant density affected plant height differently between the two planting dates. Plant heights for the first planting was slightly higher compared to the second planting. The difference in plant height between the two planting dates for the 2017/18 season was not as profound when compared to the 2016/17 season.

Plant height was affected differently between the two seasons, with plant height affected to a greater extent by maturity group during the 2017/18 season, by plant density during the 2016/17 season and by row width during both seasons. Within both seasons, plant height generally increased from MG 4.5 to MG 6, as well as from 150 000 plants ha^{-1} to 600 000 plants ha^{-1}, and from 0.30 m rows to 0.60 m rows. During the 2016/17 season plant heights for the first planting were much higher compared to the second planting, while during the 2017/18 season, plant heights for the first planting were only slightly higher compared to the second planting.

This study's results were similar to the findings in Chapter 3 and 4 (see Chapter 3.4.2.2 and 4.4.2.2 for discussion).

5.4.3 Pod clearance

5.4.3.1 2016/17

Pod clearance was significantly affected by the main effects of maturity group and plant density as well as the interaction effects of MG by PD and PD by RW for both planting dates, while the interaction effect of MG by RW also affected pod clearance for the second planting date (Table 5.4).

For the first planting, pod clearance increased significantly from MG 4.5 (9.61 cm) to MG 5 (12.93 cm) as well as to MG 6 (17.38 cm) (Table 5.14). Similarly, pod clearance increased significantly with increasing plant density. Pod clearance increased from 150 000 plants ha^{-1} (10.63 cm) to 300 000 plants ha^{-1} (12.25 cm) whereafter pod clearance increased significantly to 400 000 plants ha^{-1} (14.33 cm) as well as to 600 000 plants ha^{-1} (16.06 cm) (Table 5.14). For the second planting, pod clearance increased significantly from MG 4.5 (7.28 cm) to MG 5 (12.09 cm) as well as to MG 6 (15.22 cm) (Table 5.14). Pod clearance increased with each increment increase in plant density. Pod clearance increased from 150 000 plants ha^{-1} (10.08 cm) to 300 000 plants ha^{-1} (10.67 cm) as well as to 400 000 plants ha^{-1} (12.08 cm) and 600 000 plants ha^{-1} (13.29 cm) (Table 5.14). There were significant differences in pod clearance between 600 000 plants ha^{-1} and both 150 000 plants ha^{-1} and 300 000 plants ha^{-1}, and between 400 000 plants ha^{-1} and 150 000 plants ha^{-1} (Table 5.15).

The PD by RW interaction significantly affected pod clearance (Table 5.20). Between row widths the only significant difference recorded was at 600 000 plants ha^{-1} with 0.60 m rows (18.25 cm) which recorded a significantly higher pod clearance compared to that of 0.30 m rows (13.88 cm). Between plant densities pod clearance generally increased with each increment increase in plant density. Significantly higher pod clearances were recorded at both 400 000 plants ha^{-1} and 600 000 plants ha^{-1} compared to 150 000 plants ha^{-1} at both row widths. No significant differences were further recorded except between 600 000 plants ha^{-1} (18.25 cm) and 400 000 plants ha^{-1} (14.17 cm) at 0.60 m rows.

Pod clearance for the first and second planting was significantly affected by the MG by PD interaction (Table 5.14). Within each maturity group, pod clearance generally increased with each increment in plant density. Within each plant density MG 6 recorded the highest pod clearance, significantly higher than both MG 5 and MG 4.5, except for 150 000 plants ha^{-1}. MG 5 also recorded significantly higher pod clearances compared to those of MG 4.5 at each plant density except at 300 000 plants ha^{-1}. For the second planting within each maturity group, pod clearance generally increased with each increase in plant density. Within each plant density increment MG 6 recorded the highest pod clearance, significantly higher compared to MG 4.5 at all plant densities and MG 5 only at 300 000 plants ha^{-1} and 600 000 plants ha^{-1}. MG 5 recorded a significantly higher pod clearance compared to that of MG 4.5 at all plant densities, except at 300 000 plants ha^{-1}. For both plantings maturity group and plant density contributed equally to pod clearance being significantly affected by this interaction.

Pod clearance for the second planting was significantly affected by the MG by PD interaction (Table 5.15). Within each maturity group the 0.30 m rows recorded the highest pod clearance, but not to any significant extent. Within each row width MG 6 recorded the highest pod clearance, followed by MG 5, with both recording a significantly higher pod clearance compared to MG 4.5. Only maturity group contributed to pod clearance having a significant effect due to this interaction.

Pod clearance for the first and second planting was significantly affected by the PD by RW interaction (Table 5.16). Within each row width, pod clearance generally increased with each increment in plant density. Within each plant density increment between row widths, 0.30 m rows recorded the highest pod clearances, but with no significant difference, except at 600 000 plant ha^{-1} where 0.60 m rows recorded the significantly highest pod clearance. For the second planting within each row width, pod clearance increased with each increment increase in plant density. Within each plant density increment between row widths, 0.30 m rows recorded the highest pod clearances, but with no significant difference. For both plantings plant density contributed more to pod clearance being significantly affected by this interaction.

Table 5.14 Effect of maturity group and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	7.25	11.00	13.63	10.63
300 000	9.50	10.63	16.63	12.25
400 000	10.63	15.00	17.38	14.33
600 000	11.06	15.25	21.88	16.06
Mean	9.61	12.90	17.38	
Second planting				
150 000	6.38	11.00	12.88	10.08
300 000	7.38	10.50	14.13	10.67
400 000	7.63	13.13	15.50	12.08
600 000	7.75	13.75	18.38	13.29
Mean	7.28	12.09	15.22	

First planting
MG $_{LSD\ (\leq 0.05)}$ =1.64
PD $_{LSD\ (\leq 0.05)}$ = 1.64
MG x PD $_{LSD\ (\leq 0.05)}$ = 3.41

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.12
PD $_{LSD\ (\leq 0.05)}$ = 1.78
MG x PD $_{LSD\ (\leq 0.05)}$ = 3.46

Table 5.15 Effect of maturity group and row width on pod clearance (cm)

Row width	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	9.09	13.00	16.75	12.95
0.60 m	10.13	12.94	18.00	13.69
Mean	9.61	12.97	17.38	
Second planting				
0.30 m	7.31	13.06	15.31	11.90
0.60 m	7.25	11.13	15.13	11.17
Mean	7.28	12.09	15.22	

First planting
MG $_{LSD (\leq 0.05)}$ = 1.64
RW $_{LSD (\leq 0.05)}$ = ns
MG x RW $_{LSD (\leq 0.05)}$ = ns

Second planting
MG $_{LSD (\leq 0.05)}$ = 2.12
RW $_{LSD (\leq 0.05)}$ = ns
MG x RW $_{LSD (\leq 0.05)}$ = 3.74

Table 5.16 Effect of row width and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	**Row width**		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	10.92	10.33	10.63
300 000	12.50	12.00	12.25
400 000	14.50	14.17	14.33
600 000	13.88	18.25	16.06
Mean	12.95	13.6	
Second planting			
150 000	10.08	10.08	10.08
300 000	10.75	10.58	10.67
400 000	13.17	11.00	12.08
600 000	13.58	13.00	13.29
Mean	11.90	11.17	

First planting
PD $_{LSD (\leq 0.05)}$ = 1.64
RW $_{LSD (\leq 0.05)}$ = ns
RW x PD $_{LSD (\leq 0.05)}$ = 2.57

Second planting
PD $_{LSD (\leq 0.05)}$ = 1.78
RW $_{LSD (\leq 0.05)}$ = ns
PD x RW $_{LSD (\leq 0.05)}$ = 2.60

5.4.3.2 2017/18

Pod clearance was significantly affected by the main effects of maturity group as well as the interaction effects of MG by PD and MG by RW for both planting dates, while the row width main effect also affected pod clearance for the second plating date (Table 5.5).

For the first planting, pod clearance increased significantly from MG 4.5 (8.88 cm) to MG 5 (20.13 cm) as well as to MG 6 (30.38 cm) (Table 5.17). For the second planting, pod clearance increased significantly from MG 4.5 (8.69 cm) to MG 5 (20.16 cm) as well as to MG 6 (29.69 cm) (Table 5.17). Between row widths, the 0.60 m rows recorded the significantly highest pod clearance (19.81 cm) compared to that of 0.30 m rows (19.21 cm) (Table 5.18).

Pod clearance for the first and second planting was significantly affected by the MG by PD interaction (Table 5.17). For the first planting within each plant density increment MG 6 recorded the significantly highest pod clearance compared to MG 5 and MG 4.5, while MG 5 recorded a significantly higher pod clearance compared to MG 4.5. Within each maturity group there were no specific trends in pod clearance, with the only significant variation within MG 6. For the second planting within each plant density increment, MG 6 recorded the significantly highest pod clearance compared to MG 5 and MG 4.5, while MG 5 recorded a significantly higher pod clearance compared to MG 4.5. Within each maturity group there were no specific trends in pod clearance, with the only significant evidence within MG 6. For both plantings, maturity group contributed more to pod clearance being significantly affected by this interaction.

Table 5.17 Effect of maturity group and plant density on pod clearance (cm)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	8.75	20.00	31.13	19.96
300 000	9.13	19.63	29.25	19.33
400 000	9.00	20.63	29.50	19.71
600 000	8.63	20.25	31.63	20.17
Mean	8.88	20.13	30.38	
Second planting				
150 000	8.63	20.50	28.25	19.13
300 000	8.63	19.88	30.50	19.67
400 000	9.13	20.50	29.75	19.79
600 000	8.38	19.75	30.25	19.46
Mean	8.69	20.16	29.69	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.80
PD $_{LSD\ (\leq 0.05)}$ = ns
MG x PD $_{LSD\ (\leq 0.05)}$ = 1.66

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.52
PD $_{LSD\ (\leq 0.05)}$ = ns
MG x PD $_{LSD\ (\leq 0.05)}$ = 1.52

Pod clearance for the first and second planting was significantly affected by the MG by RW interaction (Table 5.18). For the first planting and second planting within each row width, MG 6 recorded the significantly highest pod clearance, followed by MG 5 and MG 4.5, also with significant difference between the latter two. For the second planting between row width 0.60 m rows recorded a significantly higher pod clearance compared to 0.30 m rows within MG 6 only. For both planting dates, maturity group contributed more to the significant effect of the interaction on pod clearance.

Table 5.18 Effect of maturity group and row width on pod clearance (cm)

Row width	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	8.81	20.19	30.56	19.85
0.60 m	8.94	20.06	30.19	19.73
Mean	8.88	20.13	30.38	
Second planting				
0.30 m	8.63	20.13	28.88	19.21
0.60 m	8.75	20.19	30.50	19.81
Mean	8.69	20.16	29.69	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.80
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = 0.92

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.52
RW $_{LSD\ (\leq 0.05)}$ = 0.35
MG x RW $_{LSD\ (\leq 0.05)}$ = 0.92

For the 2016/17 season, pod clearance was affected similarly by maturity group and plant density between both planting dates. For both planting dates pod clearance increased significantly from MG 4.5 to MG 5, as well as to MG 6, while pod clearance also increased significantly with increasing plant density. The pod clearances recorded for the first planting were slightly higher, on average 1 to 2 cm, compared to the second planting. While only maturity group and plant density, as well as the interaction effects significantly affected pod clearance, row width had no significant effect on pod clearance. Maturity group and plant density were thus the two factors affecting pod clearance significantly.

For the 2017/18 season pod clearance was affected by maturity group for the first planting as well as row width for the second planting. For both planting dates, pod clearance increased significantly from MG 4.5 to MG 5, as well as to MG 6. For the second planting, row width also affected pod clearance significantly with 0.60 m rows recording a significantly higher pod clearance, although this significant difference was very slight/not profound (less than 1 cm or <5%). Similar to the 2016/17 season, the pod clearances recorded for the first planting was slightly higher, on average 1 to 2 cm (± 12%), compared to the second planting. It has to be noted that the pod clearance of the 2017/18 season was ± 7 cm higher than that of the 2016/17 season. While only maturity group and plant density, as well as the interaction effects significantly affected pod clearance, and row width having only a very small significant effect on pod clearance during the second planting, maturity group and plant density were thus the two factors affecting pod clearance most significantly.

Pod clearance was affected in the same way and by the same factors between both seasons and both planting dates. This study's results were similar to the findings set out in Chapter 3 and 4 (see Chapter 3.4.2.2 and 4.4.2.2 for discussion).

5.4.4 Number of pods per plant

5.4.4.1 2016/17

The number of pods per plant was significantly affected by the main effect of plant density as well as the interaction effect of MG by PD and PD by RW for both planting dates. Maturity group and row width's main effects, as well as the interaction effect of MG by RW, also affected the number of pods per plant significantly at the second planting date (Table 5.4).

For the first planting, plant density significantly affected the number of pods per plant, with the greatest number of pods per plant recorded at 150 000 plants ha^{-1} (70.67), whereafter decreasing significantly to 300 000 plants ha^{-1} (52.28) as well as to 400 000 plants ha^{-1} (43.70) and 600 000 plants ha^{-1} (33.83) (Table 5.19). For the second planting, maturity group significantly affected number of pods per plant with MG 4.5 recording significantly the greatest number of pods per plant (65.47), followed by MG 6 (38.50) with significantly less, and MG 5 (32.47) with significantly the least number of pods per plant (Table 5.19). Number of pods per plant decreased significantly from 150 000 plants ha^{-1} (68.13) to 300 000 plants ha^{-1} (47.67) as well as to 400 000 plants ha^{-1} (35.00) and 600 000 plants ha^{-1} (31.13) (Table 5.19). Row width also significantly affected number of pods per plant, with 0.30 m rows recording the significantly greatest number of pods per plant (50.92) followed by 0.60 m rows with significantly the least number of pods per plant (40.04) (Table 5.20).

The number of pods per plant for the first and second planting was significantly affected by the MG by PD interaction (Table 5.19). For the first and second planting there were significant differences in number of pods per plant within each maturity group. The number of pods per plant decreased with each increment in plant density. Within each plant density increment between maturity groups there were no significant differences in number of pods per plant for the first planting. However, there were significant differences for the second planting with MG 4.5 recording significantly the greatest number of pods per plant within each plant density compared to MG 5 and MG 6, with the only significant difference between the latter two at 400 000 plants ha^{-1}. For both plantings, plant density contributed to number of pods per plant being significantly affected by this interaction, while maturity group also contributed for the second planting.

Table 5.19 Effect of maturity group and plant density on number of pods per plant

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	62.48	70.53	79.01	63.63
300 000	51.90	45.94	59.00	51.68
400 000	44.59	36.93	49.60	44.39
600 000	37.45	33.08	30.96	38.67
Mean	49.10	46.62	54.64	49.59
Second planting				
150 000	93.63	53.13	57.63	68.13
300 000	64.38	37.75	40.88	47.67
400 000	53.13	20.00	31.88	35.00
600 000	50.75	19.01	23.63	31.13
Mean	65.47	32.47	38.50	

First planting
MG $_{LSD\ (\leq 0.05)}$ = ns
PD $_{LSD\ (\leq 0.05)}$ = 6.75
MG x PD $_{LSD\ (\leq 0.05)}$ = 21.03

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.45
PD $_{LSD\ (\leq 0.05)}$ = 3.78
MG x PD $_{LSD\ (\leq 0.05)}$ = 5.42

The number of pods per plant for the second planting was significantly affected by the MG by RW interaction (Table 5.20). Within MG 4.5 and MG 6, 0.30 m rows recorded the significantly greatest number of pods per plant. Within each row width, MG 4.5 significantly recorded the greatest number of pods per plant, followed by MG 6 and MG 5, with only a significant difference in number of pods per plant between the latter two at 0.30 m rows. For the second planting both maturity group and row width contributed equally to pod clearance, being significantly affected by this interaction.

Table 5.20 Effect of maturity group and row width on number of pods per plant

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	43.56	48.76	56.45	49.59
0.60 m	54.65	44.47	52.84	50.65
Mean	49.10	46.62	54.64	
Second planting				
0.30 m	78.56	33.19	41.00	50.92
0.60 m	52.38	31.75	36.00	40.04
Mean	65.4	32.47	38.50	

First planting
MG $_{LSD\ (\leq 0.05)}$ = ns
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = ns

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.45
RW $_{LSD\ (\leq 0.05)}$ = 1.65
MG x RW $_{LSD\ (\leq 0.05)}$ = 4.31

The number of pods per plant for the first and second planting was significantly affected by the PD by RW interaction (Table 5.21). For the first planting within each row width there were significant differences in number of pods per plant between plant densities, with number of pods per plant decreasing with each increment increase in plant density. For the second planting within each row width, the number of pods per plant decreased significantly with each increment increase in plant density. Within each plant density increment, 0.30 m rows recorded a significantly greater number of pods per plant compared to 0.60 m rows. For both plantings, plant density contributed to the number of pods per plant being significantly affected by this interaction, while row width also contributed for the second planting.

Table 5.21 Effect of row width and plant density on number of pods per plant

Plant density (plants ha^{-1})	Row width		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	63.63	77.72	70.67
300 000	51.58	52.88	52.28
400 000	44.39	43.02	43.70
600 000	38.67	28.99	33.83
Mean	49.59	50.65	
Second planting			
150 000	75.83	60.42	68.13
300 000	50.25	45.08	47.67
400 000	37.25	32.75	35.00
600 000	40.34	21.90	31.13
Mean	50.92	40.04	

First planting
PD $_{LSD\ (\leq 0.05)}$ = ns
RW $_{LSD\ (\leq 0.05)}$ = ns
RW x PD $_{LSD\ (\leq 0.05)}$ = 15.84

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 3.78
RW $_{LSD\ (\leq 0.05)}$ = 1.65
PD x RW $_{LSD\ (\leq 0.05)}$ = 4.08

5.4.4.2 2017/18

The number of pods per plant was significantly affected by the main effect of plant density as well as the interaction effect of MG by PD and PD by RW for both planting dates. The main effects of maturity group and row width as well as the interaction effect of MG by RW also significantly affected number of pods per plant for the second planting (Table 5.5).

For the first planting, the number of pods per plant was significantly affected by plant density, with number of pods per plant decreasing significantly from 150 000 plants ha^{-1} (60.15) to 300 000 plants ha^{-1} (45.12), as well as to 400 000 plants ha^{-1} (28.43) whereafter only decreasing to 600 000 plants ha^{-1} (21.08) (Table 5.22). For the second planting, maturity group significantly affected number of pods per plant with MG 4.5 recording significantly the greatest number of pods per plant (65.47), followed by MG 6 (38.50) with significantly less and MG 5 (32.47) with significantly the least number of pods per plant (Table 5.22). Number of pods per plant decreased significantly from 150 000 plants ha^{-1} (68.13) to 300 000 plants ha^{-1} (47.67) as well as to 400 000 plants ha^{-1} (35.00) and 600 000 plants ha^{-1} (31.13) (Table 5.22). Row width also significantly affected the number of pods per plant with 0.30 m rows recording significantly the greatest number of pods per plant (50.92) followed by 0.30 m rows with significantly the least number of pods per plant (40.04) (Table 5.23).

The number of pods per plant for the first and second planting was significantly affected by the MG by PD interaction (Table 5.22). For the first and second planting, there were significant differences in number of pods per plant within each maturity group, with number of pods per plant decreasing with each increment increase in plant density. Within each plant density increment between maturity groups there were no significant differences in number of pods per plant for the first planting, however there were significant differences for the second planting, with MG 4.5 recording significantly the greatest number of pods per plant within each plant density compared to MG 5 and MG 6, with the only significant difference between the latter two at 300 000 and 400 000 plants ha^{-1}. For both plantings plant density contributed to pod clearance being significantly affected by this interaction, while maturity group also contributed for the second planting.

The number of pods per plant for the second planting was significantly affected by the MG by RW interaction (Table 5.23). Within MG 4.5, 0.30 m rows recorded significantly the greatest number of pods per plant. Within each row width MG 4.5 recorded the significantly greatest number of pods per plant, followed by MG 6 and MG 5, with no significant difference between the latter two. For the second planting both maturity group and row width contributed to pod clearance being significantly affected by this interaction.

The number of pods per plant for the first and second planting was significantly affected by the PD by RW interaction (Table 5.24). For the first and second plantings within each row width there were significant differences in number of pods per plant between plant densities with number of pods per plant decreasing with each increment in plant density. For the second planting within each plant density increment, 0.30 m rows recorded a significantly greater number of pods per plant compared to 0.60 m rows only at 150 000 and 600 000 plants ha^{-1}. For both plantings plant density contributed to the number of pods per plant being significantly affected by this interaction, while row width also contributed for the second planting.

Table 5.22 Effect of maturity group and plant density on number of pods per plant

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	67.10	55.65	57.70	60.15
300 000	48.19	43.44	43.74	45.12
400 000	30.85	28.69	25.75	28.43
600 000	18.64	22.28	22.33	21.08
Mean	41.19	37.51	37.38	
Second planting				
150 000	93.55	54.02	50.57	66.05
300 000	65.49	33.69	45.36	48.18
400 000	56.21	20.23	31.55	35.99
600 000	51.35	18.96	23.78	31.36
Mean	66.65	31.73	37.81	

First planting
$MG_{LSD\ (\leq 0.05)}$ = ns
$PD_{LSD\ (\leq 0.05)}$ = 9.82
$MG \times PD_{LSD\ (\leq 0.05)}$ = 15.68

Second planting
$MG_{LSD\ (\leq 0.05)}$ = 4.80
$PD_{LSD\ (\leq 0.05)}$ = 4.87
$MG \times PD_{LSD\ (\leq 0.05)}$ = 10.53

Table 5.23 Effect of maturity group and row width on number of pods per plant

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	40.54	37.94	40.16	39.55
0.60 m	41.84	37.08	34.60	37.84
Mean	41.19	37.51	37.38	
Second planting				
0.30 m	79.37	33.43	40.09	50.96
0.60 m	53.93	30.02	35.54	39.83
Mean	66.65	31.73	37.81	

First planting
$MG_{LSD\ (\leq 0.05)}$ = ns
$RW_{LSD\ (\leq 0.05)}$ = ns
$MG \times RW_{LSD\ (\leq 0.05)}$ = ns

Second planting
$MG_{LSD\ (\leq 0.05)}$ = 4.80
$RW_{LSD\ (\leq 0.05)}$ = 3.23
$MG \times RW_{LSD\ (\leq 0.05)}$ = 8.46

Table 5.24 Effect of row width and plant density on number of pods per plant

Plant density (plants ha^{-1})	Row width		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	61.99	58.31	60.15
300 000	48.73	41.51	45.12
400 000	27.03	29.83	28.43
600 000	20.44	21.72	21.08
Mean	39.55	37.84	
Second planting			
150 000	75.26	56.83	66.05
300 000	50.23	46.13	48.18
400 000	37.73	34.26	35.99
600 000	40.62	22.10	31.36
Mean	50.96	39.83	

First planting
PD $_{LSD\ (\leq 0.05)}$ = 9.82
RW $_{LSD\ (\leq 0.05)}$ = ns
RW x PD $_{LSD\ (\leq 0.05)}$ = 11.81

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 4.87
RW $_{LSD\ (\leq 0.05)}$ = 3.23
PD x RW $_{LSD\ (\leq 0.05)}$ = 7.93

For the 2016/17 season the number of pods per plant was significantly affected by maturity group within both planting dates. These numbers were, however, affected differently. For the first planting, date MG 6 recorded greater number of pods per plant, followed by MG 4.5, while for the second planting MG 4.5 recorded the greatest number of pods per plant, followed by MG 6, with MG 5 recording the lowest number of pods per plant within both planting dates. Plant density affected the number of pods per plant similarly within both planting dates. The number of pods per plant decreased significantly with increased plant densities. Row width slightly affected number of pods per plant for the first planting. However, row width had a greater effect on number of pods per plant for the second planting, with 0.30 m rows recording significantly greater number of pods per plant compared to 0.60 m rows. Number of pods per plant recorded for the first planting was on average five (5) pods per plant more, than when compared to the second planting. Maturity group and plant density affected number of pods per plant significantly for both planting dates, while row width only affected number of pods per plant for the second planting.

For the 2017/18 season maturity group significantly affected number of pods per plant only for the second planting, with MG 4.5 recording significantly the greatest number of pods per plant, followed by MG 6, with MG 5 recording significantly the lowest number of pods per plant. Plant density affected number of pods per plant significantly for both planting dates, with number of pods per plant decreasing with increased plant density. Row width also affected number of pods per plant significantly only for the second planting with 0.30 m rows recording a significantly greater number of pods per plant compared to 0.60 m rows. Number of pods per plant recorded for the first planting was on average five to ten (5-10) pods per plant less, than when compared to the second planting. Plant density affected the number of pods per plant most, while maturity group and row width had a significant effect only for the second planting.

This study's results are similar to the findings in Chapter 3 and 4 (See chapter 3.4.4.2 and 4.4.4.2 for discussion). The decrease in the number of pods per plant due to an increase in plant density is argued as a contributing factor to increased competition between plants with increasing plant densities for nutrients, moisture, and sunlight. This might also be due to the development and vigorous leaf growth of low plant densities and improved photosynthetic efficiency, which result in a larger number of pods per plant. This agrees with Abdel (2008) and Lopez-Bellido *et al*., (2005) who state that soya beans, common bean and faba bean display considerable plasticity in response to varying plant densities, especially in terms of number of pods per plant. According to Kumagai and Takahashi (2020) planting date affected number of pods per plant with delayed planting resulting in a lower number of pods per plant compared to normal/earlier planting dates. This result is only in agreement with the 2016/17 season's findings.

5.4.5 Number of seeds per pod

Analysis of variance indicated that the interaction effect of maturity group, plant density and row width resulted in no significant differences in number of seeds per pod for both the 2016/17 and 2017/18 season. The number of seeds per pod was also not significantly affected by either one of the main effects for both seasons. (Data not shown). This result is similar to the findings in Chapter 3 (see Chapter 3.4.5 for discussion).

5.4.6 Hundred-seed weight

5.4.6.1 2016/17

Hundred-seed weight was significantly affected by the main effects of maturity group and plant density as well as the interaction effects of MG by PD, MG by RW and PD by RW for both planting dates, while hundred-seed weight was also significantly affected by the main effect of row width for the second planting (Table 5.4).

For the first planting, hundred-seed weight was significantly affected by maturity group with MG 4.5 (18.88 g) recording the greatest hundred-seed weight, followed by MG 6 (17.46 g) and MG 5 (12.51 g), with both MG 4.5 and MG 6 recording a significantly greater hundred-seed weight than that of MG 5, with no significant difference between MG 4.5 and MG 6 (Table 5.25). Hundred-seed weight decreased from 150 000 plants ha^{-1} (19.90 g) to 300 000 plants ha^{-1} (15.80 g) whereafter it decreased to only 400 000 plants ha^{-1} (15.53 g) and to 600 000 plants ha^{-1} (13.91 g) (Table 5.25). There were no significant differences in hundred-seed weight between 300 000, 400 000 and 600 000 plants ha^{-1}. For the second planting, maturity group significantly affected hundred-seed weight with MG 5 recording significantly the greatest hundred-seed weight (14.47 g), followed by MG 6 (9.85 g) and MG 4.5 (9.11 g), both significantly lower than MG 5 (Table 5.25). The greatest hundred-seed weight was recorded at 400 000 plants ha^{-1} (14.11 g), followed by 600 000 plants ha^{-1} (13.83 g), 150 000 plants ha^{-1} (11.45 g) which were significantly lower than 400 000 plants ha^{-1}, with the lowest hundred-seed weight recorded at 300 000 plants ha^{-1} (9.41 g), which were significantly lower than both 400 000 plants ha^{-1} and 600 000 plants ha^{-1} (Table 5.25). Row width also affected hundred-seed weight significantly, with 0.60 m rows recording the greatest hundred-seed weight (12.20 g), followed by 0.30 m rows (10.08 g) (Table 5.26).

The hundred-seed weight for the first and second planting was significantly affected by the MG by PD interaction (Table 5.25). For the first planting, there were significant differences between plant densities within MG 4.5 and 6, with hundred-seed weight generally decreasing with each increment increase in plant density. Within each plant density increment MG 4.5 generally recorded a significantly greater hundred-seed weight compared to MG 5, while MG 6 recorded a significantly greater hundred-seed weight compared to MG 5 only at 150 000 plants ha^{-1}. For the second planting, there were significant differences between plant densities within MG 5 only, with a slightly increasing trend with increased plant density. Within each plant density increment generally the greatest hundred-seed weight was recorded for MG 5, followed by MG 6 and MG 4.5. The only significant difference in hundred-seed weight occurred at 400 000 and 600 000 plants ha^{-1} between MG 5 and MG 4.5. For both plantings, maturity group and plant density equally contributed to hundred-seed weight being significantly affected by this interaction.

Hundred-seed weight for the first and second planting was significantly affected by the MG by RW interaction (Table 5.26). For the first planting within each maturity group 0.30 m row recorded a greater hundred-seed weight compared to 0.60 m rows, although this was not considered significant. Within each row width MG 4.5 recorded the greatest hundred-seed weight, followed by MG 6, with both recording a significantly greater hundred-seed weight compared to MG 5. For the second planting within MG 4.5 and MG 5, 0.60 m rows recorded significantly the greatest hundred-seed weight compared to 0.30 m rows. Within each row width, MG 5 recorded the significantly greatest hundred-seed weight compared to MG 4.5, while MG 5 also recorded a significantly greater hundred-seed weight compared to MG 6 at 0.60 m rows. For both plantings, maturity group contributed to hundred-seed weight being significantly affected by this interaction, while row width also contributed in the second planting.

Hundred-seed weight for the first and second planting was significantly affected by the PD by RW interaction (Table 5.27). For the first planting within each row width there were significant differences recorded between plant density increments, with hundred-seed weight generally decreasing with each increment increase in plant density. Within each plant density increment, 0.30 m rows generally recorded the greatest hundred-seed weight, but with no significance. For the second planting within each row width there were only significant differences between plant density increments for 0.60 m rows, while within plant density increments, 0.60 m rows generally recorded the greatest hundred-seed weight, but with no significance. For both plantings only plant density contributed to hundred-seed weight being significantly affected by this interaction.

Table 5.25 Effect of maturity group and plant density on hundred-seed weight (g)

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	22.72	13.64	23.33	19.90
300 000	17.94	13.53	16.08	15.80
400 000	18.65	12.99	14.93	15.53
600 000	16.35	9.87	15.50	13.91
Mean	18.88	12.51	17.46	
Second planting				
150 000	9.25	12.96	7.58	9.91
300 000	8.47	9.98	10.16	9.54
400 000	8.95	19.92	10.58	13.15
600 000	9.76	15.01	11.15	11.97
Mean	9.11	14.47	9.85	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 2.05
PD $_{LSD\ (\leq 0.05)}$ = 2.58
MG x PD $_{LSD\ (\leq 0.05)}$ = 5.76

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.30
PD $_{LSD\ (\leq 0.05)}$ = 3.77
MG x PD $_{LSD\ (\leq 0.05)}$ = 5.09

Table 5.26 Effect of maturity group and row width on hundred-seed weight (g)

Row width	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	19.83	13.01	17.99	16.94
0.60 m	17.93	12.02	16.93	15.63
Mean	18.88	12.51	17.46	
Second planting				
0.30 m	6.99	12.26	10.99	10.08
0.60 m	11.21	16.67	8.71	12.20
Mean	9.11	14.47	9.85	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 2.05
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = 3.60

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 2.30
RW $_{LSD\ (\leq 0.05)}$ = 1.55
MG x RW $_{LSD\ (\leq 0.05)}$ = 4.06

Table 5.27 Effect of row width and plant density on hundred-seed weight (g)

Plant density (plants ha^{-1})	**Row width**		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	19.53	20.27	19.90
300 000	17.26	14.34	15.80
400 000	15.86	15.20	15.53
600 000	15.13	12.69	13.91
Mean	16.94	15.63	
Second planting			
150 000	8.37	11.45	9.91
300 000	9.66	9.41	9.54
400 000	12.19	14.11	13.15
600 000	10.12	13.83	11.97
Mean	10.08	12.20	

First planting
PD $_{LSD\ (\leq 0.05)}$ = 2.58
RW $_{LSD\ (\leq 0.05)}$ = ns
RW x PD $_{LSD\ (\leq 0.05)}$ = 4.34

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 3.77
RW $_{LSD\ (\leq 0.05)}$ = 1.55
PD x RW $_{LSD\ (\leq 0.05)}$ = 3.83

5.4.6.2 2017/18

Hundred-seed weight was significantly affected by the main effects of maturity group and plant density as well as by the interaction effect of MG by PD, MG by RW and PD by RW for the first planting (Table 5.5). For the second planting there were no significant effects on hundred-seed weight.

For the first planting the greatest hundred-seed weight was recorded for MG 6 (16.29 g), followed by MG 5 (14.12 g) and MG 4.5 (13.81 g), with the only significant difference occurring between MG 6 and MG 4.5 (Table 5.28). Hundred-seed weight decreased from 150 000 plants ha^{-1} (17.88 g) to 300 000 plants ha^{-1} (15.13 g) as well as to 400 000 plants ha^{-1} (13.68 g) and 600 000 plants ha^{-1} (12.28 g), with the only significant difference between 150 000 plants ha^{-1} and 600 000 plants ha^{-1} (Table 5.29).

Hundred-seed weight for the first planting was significantly affected by the MG by PD interaction (Table 5.28). Within each maturity group, hundred-seed weight generally decreased with each increment increase in plant density, with the only significant difference occurring in grain yield recorded for MG 5. Within each plant density increment there was no significant difference in grain yield recorded between maturity groups. For the first planting, only maturity group contributed to hundred-seed weight being significantly affected by this interaction.

Hundred-seed weight for the first planting was significantly affected by the MG by RW interaction (Table 5.29). The only significant difference recorded in the hundred-seed weight was within 0.30 m rows with MG 6 recording a significantly greater hundred-seed weight compared to MG 4.5.

Hundred-seed weight for the first planting was significantly affected by the PD by RW interaction (Table 5.30). Within each row width there were significant differences in hundred-seed weight between plant densities, with hundred-seed weight decreasing with each increment in plant density. Within each plant density increment, there were no significant difference in hundred-seed weight between row widths. For the first planting only plant density contributed to hundred-seed weight being significantly affected by this interaction.

Table 5.28 Effect of maturity group and plant density on hundred-seed weight (g)

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	16.80	18.74	18.11	17.88
300 000	14.31	14.53	16.53	15.13
400 000	11.74	12.35	16.94	13.68
600 000	12.41	10.84	13.58	12.28
Mean	13.81	14.12	16.29	
Second planting				
150 000	13.28	13.15	13.22	13.22
300 000	13.14	13.47	13.20	13.27
400 000	13.40	13.39	13.34	13.38
600 000	13.67	13.22	13.29	13.39
Mean	13.37	13.31	13.26	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 2.27
PD $_{LSD\ (\leq 0.05)}$ = ns
MG x PD $_{LSD\ (\leq 0.05)}$ = 5.52

Second planting
MG $_{LSD\ (\leq 0.05)}$ = ns
PD $_{LSD\ (\leq 0.05)}$ = ns
MG x PD $_{LSD\ (\leq 0.05)}$ = ns

Table 5.29 Effect of maturity group and row width on hundred-seed weight (g)

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	13.32	14.17	17.85	15.11
0.60 m	14.31	14.07	14.73	14.37
Mean	13.81	14.12	16.29	
Second planting				
0.30 m	13.55	13.47	13.22	13.41
0.60 m	13.19	13.15	13.30	13.21
Mean	13.37	13.31	13.26	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 2.27
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = 3.99

Second planting
MG $_{LSD\ (\leq 0.05)}$ = ns
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = ns

Table 5.30 Effect of row width and plant density on hundred-seed weight (g)

Plant density (plants ha^{-1})	Row width		
	0.30 m	0.60 m	Mean
First planting			
150 000	17.68	18.08	17.88
300 000	15.08	15.17	15.13
400 000	14.59	12.76	13.68
600 000	13.11	11.45	12.28
Mean	15.11	14.37	
Second planting			
150 000	13.20	13.24	13.22
300 000	13.59	12.95	13.27
400 000	13.31	13.44	13.38
600 000	13.56	13.23	13.39
Mean	13.41	13.21	

First planting
PD $_{LSD (\leq 0.05)}$ = ns
RW $_{LSD (\leq 0.05)}$ = ns
RW x PD $_{LSD (\leq 0.05)}$ = 4.16

Second planting
PD $_{LSD (\leq 0.05)}$ = ns
RW $_{LSD (\leq 0.05)}$ = ns
PD x RW $_{LSD (\leq 0.05)}$ = ns

For the 2016/17 season, maturity group affected hundred-seed weight significantly for both plantings. However, the hundred-seed weight of each maturity group was affected differently within each planting. For the first planting, MG 4.5 recorded the greatest hundred-seed weight, followed by MG 6, with MG 5 recording the lowest hundred-seed weight, while for the second planting MG 5 recorded the greatest hundred-seed weight, followed by MG 6, with MG 4.5 recording with the lowest hundred-seed weight. Plant density also affected hundred-seed weight significantly for both plantings, but these were also affected differently within each planting. For the first planting, hundred-seed weight decreased significantly with increasing plant density, while for the second planting hundred-seed weight increased significantly with increasing plant density. Row width affected hundred-seed weight significantly only within the second planting, with 0.60 m rows recording a significantly greater hundred-seed weight compared to 0.30 m rows. Hundred-seed weight recorded for the first planting was considerably greater (on average 5 g) compared to the second planting. Hundred-seed weight was significantly affected more by maturity group and plant density, while row width only had an effect during the second planting.

For the 2017/18 season, hundred-seed weight was significantly affected by maturity group, plant density and row width only within the first planting. Surprisingly within the second planting no treatment or treatment combinations affected hundred-seed weight significantly. For the first planting, hundred-seed weight increased significantly from MG 4.5 to MG 5 and MG 6. Hundred-seed weight decreased significantly with increasing plant density. Hundred-seed weight in the first planting was also considerably greater (on average 2 to 4 g) compared to the second planting, but the difference between plantings was slightly less compared to the 2016/17 season. Maturity group affected hundred-seed weight the most, while plant density also had an effect on hundred-seed weight. This study's results differ from the findings in chapter 3 and 4 (See Chapter 3.4.6.2 and 4.4.6.2 for discussion). In agreement with this study Kumagai and Takahashi (2020) reported that delayed planting resulted in lower hundred-seed weight compared to a normal/earlier planting date.

5.4.7 Yield (t ha^{-1})

5.2.7.1 2016/17

Grain yield was significantly affected by the main effects of maturity group and row width as well as by the interaction effect of MG by PD, MG by RW and PD by RW for both planting dates, while grain yield was also significantly affected by the plant density main effect for the second planting (Table 5.4)

For the first planting, the greatest grain yield was recorded at MG 6 (5.01 t ha^{-1}), followed by MG 5 (4.60 t ha^{-1}) and MG 4.5 (4.10 t ha^{-1}) (Table 5.31). The only significant difference was recorded between MG 6 and MG 4.5. Row width also had a significant effect on grain yield, with 0.30 m rows (4.98 t ha^{-1}) recording a significantly greater grain yield than that of the 0.60 m rows (4.16 t ha^{-1}) (Table 5.32). For the second planting, maturity group significantly affected grain yield with MG 5 recording significantly the greatest grain yield (3.77 t ha^{-1}), followed by MG 4.5 (2.85 t ha^{-1}), which were significantly lower than MG 5, and MG 6 which recorded significantly the lowest grain yield (2.18 t ha^{-1}) (Table 5.31). Grain yield increased significantly from 150 000 plants ha^{-1} (2.46 t ha^{-1}) to 300 000 plants ha^{-1} (2.85 t ha^{-1}), as well as to 400 000 plants ha^{-1} (3.10 t ha^{-1}) and furthermore increased, albeit insignificantly, to 600 000 plants ha^{-1} (3.32 t ha^{-1}) (Table 5.31). Row width also affected grain yield significantly, with 0.30 m rows recording the significantly greatest grain yield (3.14 t ha^{-1}), followed by 0.60 m rows (2.73 t ha^{-1}) (Table 5.32).

Grain yield for the first and second planting was significantly affected by the MG by PD interaction (Table 5.31). For the first planting within each maturity group and between each plant density increment there was no significant difference in grain yield. Within each plant density increment, MG 6 generally recorded the greatest grain yield, followed by MG 5 and MG 4.5, with the only significant difference in grain yield within each plant density recorded for 150 000 plants ha^{-1} between MG 6 and MG 4.5.For the second planting within each maturity group and between plant density increment, grain yield increased with each increment in plant density, with the only significant difference in grain yield for MG 6 between 150 000 and 600 000 plants ha^{-1}. Within each plant density increment, MG 5 recorded the greatest grain yield, followed by MG 4.5 and MG 6. For both plantings only maturity group contributed to grain yield being significantly affected by this interaction.

Grain yield for the first and second planting was significantly affected by the MG by RW interaction (Table 5.32). For the first planting within MG 5 and MG 6, 0.30 m rows recorded the significantly greatest grain yield compared to 0.60 m rows. Within each row width, MG 6 recorded the significantly greatest grain yield, followed by MG 5 and MG 4.5, with no significant difference in the 0.60 m rows. For the second planting within each maturity group, 0.30 m rows recorded the greatest grain yield compared to 0.60 m rows, but not to a significant degree. Within each row width MG 5 recorded the greatest grain yield, followed by MG 4.5 and MG 6, with MG 5 recording a grain yield significantly greater only than MG 6. For both plantings, maturity group contributed to grain yield being significantly affected by this interaction, while row width also contributed in the first planting.

The grain yield for the first and second planting was significantly affected by the PD by RW interaction (Table 5.33). For the first planting within each row width between plant densities, there were no significant differences in grain yield, while within each plant density increment the only significant differences in grain yield was recorded for 600 000 plants ha^{-1} rows between 0.30 m and 0.60 m rows. For the second planting within each row width, grain yield increased with each increment in plant density, with 600 000 plants ha^{-1} recording a significantly greater grain yield compared to 150 000 plants ha^{-1} at both row widths. Within each plant density increment there was no significant difference in grain yield between row widths. For the first planting only row width contributed to grain yield, being significantly affected by this interaction, while only plant density contributed in the second planting.

Table 5.31 Effect of maturity group and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	3.68	4.40	5.20	4.43
300 000	4.05	4.24	4.92	4.40
400 000	4.54	4.99	4.71	4.83
600 000	4.14	4.77	4.96	4.62
Mean	4.10	4.60	5.01	
Second planting				
150 000	2.49	3.42	1.47	2.46
300 000	2.75	3.51	2.28	2.85
400 000	2.85	4.05	2.39	3.10
600 000	3.29	4.08	2.57	3.32
Mean	2.85	3.77	2.18	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.45
PD $_{LSD\ (\leq 0.05)}$ =ns
MG x PD $_{LSD\ (\leq 0.05)}$ = 1.02

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.59
PD $_{LSD\ (\leq 0.05)}$ = 0.34
MG x PD $_{LSD\ (\leq 0.05)}$ = 1.07

Table 5.32 Effect of maturity group and row width on grain yield (t ha^{-1})

Row width	Maturity group			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	4.25	5.02	5.94	4.98
0.60 m	3.96	4.18	4.35	4.16
Mean	4.10	4.60	5.01	
Second planting				
0.30 m	3.07	3.94	2.40	3.14
0.60 m	2.63	3.59	1.96	2.73
Mean	2.85	3.77	2.18	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.45
RW $_{LSD\ (\leq 0.05)}$ = 0.30
MG x RW $_{LSD\ (\leq 0.05)}$ = 0.79

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.59
RW $_{LSD\ (\leq 0.05)}$ = 0.40
MG x RW $_{LSD\ (\leq 0.05)}$ = 1.04

Table 5.33 Effect of row width and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Row width		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	4.67	4.18	4.43
300 000	4.75	4.06	4.40
400 000	5.16	4.51	4.83
600 000	5.33	3.91	4.62
Mean	4.98	4.16	
Second planting			
150 000	2.66	2.26	2.46
300 000	3.05	2.65	2.85
400 000	3.34	2.85	3.10
600 000	3.49	3.15	3.32
Mean	3.14	2.73	

First planting
PD $_{LSD\ (\leq 0.05)}$ = ns
RW $_{LSD\ (\leq 0.05)}$ = 0.30
RW x PD $_{LSD\ (\leq 0.05)}$ = 0.77

Second planting
PD $_{LSD\ (\leq 0.05)}$ = 0.34
RW $_{LSD\ (\leq 0.05)}$ = 0.40
PD x RW $_{LSD\ (\leq 0.05)}$ = 0.81

5.4.7.2 2017/18

Grain yield was significantly affected by the main effect of maturity group as well as by the interaction effect of MG by PD and MG by RW for both planting dates. Grain yield was also significantly affected by plant density and row width as main effects, as well as the PD by RW interaction (Table 5.5).

For the first planting, maturity group had the only significant effect on grain yield with MG 5 recording significantly the greatest grain yield (3.80 t ha^{-1}), followed by MG 6 (3.40 t ha^{-1}) and MG 4.5 (3.27 t ha^{-1}), with no significant difference between the latter two maturity groups (Table 5.34). For the second planting, maturity group significantly affected grain yield with MG 4.5 significantly recording the greatest grain yield 3.22 t ha^{-1}, followed by MG 5 (2.44 t ha^{-1}) and MG 6 (2.23 t ha^{-1}) (Table 5.34). Grain yield generally increased with each increment in plant density (Table 5.34). The greatest grain yield (2.83 t ha^{-1}) was recorded at 400 000 plants ha^{-1} followed by 600 000 plants ha^{-1} (2.83 t ha^{-1}), 300 000 plants ha^{-1} (2.59 t ha^{-1}) and 150 000 plants ha^{-1} (2.18 t ha^{-1}). Both 400 000 and 600 000 plants ha^{-1} recorded a significantly greater grain yield than 300 000 and 150 000 plants ha^{-1}, with 150 000 plants ha^{-1} recording the significant lowest grain yield. There was no significant difference in grain yield between 400 000 and 600 000 plants ha^{-1}. Row width also affected grain yield significantly with 0.30 m rows significantly recording the greatest grain yield (2.70 t ha^{-1}) compared to 0.60 m rows (2.56 t ha^{-1}) (Table 5.35).

Grain yield for the first and second planting was significantly affected by the MG by PD interaction (Table 5.34). For the first planting within each maturity group and between plant density increments there were no significant differences in grain yield, while within each plant density increment between maturity groups there were significant differences only for 150 000 plants ha^{-1} between MG 5 and MG 6, and for 400 000 plants ha^{-1} between MG 4.5 and MG 5. For the second planting, there were significant differences between plant density increments in grain yield within each maturity group, with grain yield having an increasing trend with increased plant density. Within each plant density increment MG 4.5 generally recorded the significantly greatest grain yield, generally followed by MG 5 and MG 6 with no significant difference between the latter two. For the first planting, only maturity group contributed to grain yield being significantly affected by this interaction, while maturity group and plant density contributed in the second planting.

Grain yield for the first and second planting was significantly affected by the MG by RW interaction (Table 5.35). For the first planting within each maturity group there was no significant difference in grain yield between row widths. Within each row width there were significant differences in grain yield between maturity groups, with MG 5 significantly recording the greatest grain yield compared to MG 4.5 at 0.30 m rows and MG 6 at 0.60 m rows. For the second planting within each maturity group there were also no significant differences in grain yield between row widths. Within each row width there were significant differences in grain yield between maturity groups, with MG 4.5 significantly recording the greatest grain yield compared to MG 5 and MG 6 at both row widths, while MG 5 also recorded a significantly greater grain yield compared to MG 6 at 0.30 m rows only. For both planting dates only maturity group contributed to grain yield being significantly affected by this interaction.

Grain yield for the second planting was significantly affected by the PD by RW interaction (Table 5.36). Within each row width between plant density increments there were significant differences in grain yield, with grain yield generally increasing with each increment in plant density. Within each plant density increment there were no significant differences in grain yield between row widths. For the second planting, plant density mainly contributed to grain yield being significantly affected by this interaction.

Table 5.34 Effect of maturity group and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
150 000	3.45	3.78	3.13	3.45
300 000	3.43	3.95	3.48	3.62
400 000	3.07	3.74	3.62	3.48
600 000	3.14	3.73	3.37	3.42
Mean	3.27	3.80	3.40	
Second planting				
150 000	2.85	1.88	1.80	2.18
300 000	3.05	2.63	2.09	2.59
400 000	3.67	2.67	2.41	2.92
600 000	3.29	2.57	2.62	2.83
Mean	3.22	2.44	2.23	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.28
PD $_{LSD\ (\leq 0.05)}$ = ns
MG x PD $_{LSD\ (\leq 0.05)}$ = 0.61

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.14
PD $_{LSD\ (\leq 0.05)}$ = 0.24
MG x PD $_{LSD\ (\leq 0.05)}$ = 0.54

Table 5.35 Effect of maturity group and row width on grain yield (t ha^{-1})

Row width	**Maturity group**			
	4.5	**5**	**6**	**Mean**
First planting				
0.30 m	3.11	3.91	3.63	3.55
0.60 m	3.44	3.70	3.17	3.44
Mean	3.27	3.80	3.40	
Second planting				
0.30 m	3.29	2.55	2.27	2.70
0.60 m	3.14	2.33	2.19	2.56
Mean	3.22	2.44	2.23	

First planting
MG $_{LSD\ (\leq 0.05)}$ = 0.28
RW $_{LSD\ (\leq 0.05)}$ = ns
MG x RW $_{LSD\ (\leq 0.05)}$ = 0.50

Second planting
MG $_{LSD\ (\leq 0.05)}$ = 0.14
RW $_{LSD\ (\leq 0.05)}$ = 0.10
MG x RW $_{LSD\ (\leq 0.05)}$ = 0.25

Table 5.36 Effect of row width and plant density on grain yield (t ha^{-1})

Plant density (plants ha^{-1})	Row width		
	0.30 m	**0.60 m**	**Mean**
First planting			
150 000	3.61	3.30	3.45
300 000	3.69	3.54	3.62
400 000	3.49	3.47	3.48
600 000	3.40	3.43	3.42
Mean	3.55	3.44	
Second planting			
150 000	2.27	2.08	2.18
300 000	2.74	2.45	2.59
400 000	2.81	3.02	2.92
600 000	2.99	2.67	2.83
Mean	2.70	2.56	

First planting
$PD_{LSD\ (\leq 0.05)}$ = ns
$RW_{LSD\ (\leq 0.05)}$ = ns
RW x $PD_{LSD\ (\leq 0.05)}$ = ns

Second planting
$PD_{LSD\ (\leq 0.05)}$ = 0.24
$RW_{LSD\ (\leq 0.05)}$ = 0.10
PD x $RW_{LSD\ (\leq 0.05)}$ = 0.41

For the 2016/17 season, maturity group significantly affected grain yield, with grain yield increasing significantly from MG 4.5 to MG 6 for the first planting, while for the second planting the greatest grain yield was recorded for MG 5, followed by MG 4.5 and MG 6, with significant differences in grain yield between all three maturity groups. Plant density only had a significant effect on grain yield during the second planting with grain yield increasing significantly with increased plant density. Row width also affected grain yield for both planting dates with 0.30 m rows recording a greater grain yield compared to 0.60 m rows. The grain yield recorded for the first planting was considerably greater (on average 1.6 t ha^{-1}) compared to the second planting. Grain yield was most significantly affected by maturity group and row width, while plant density only had a significant effect on grain yield during the second planting.

For the 2017/18 season, maturity group significantly affected grain yield, with MG 5 recording significantly the greatest grain yield, followed by MG 6 and MG 4.5 for the first planting, while for the second planting grain yield decreased significantly from MG 4.5 to MG 5 as well as to MG 6. Plant density only affected grain yield significantly during the second planting, with grain yield increasing with increased plant density. Row width affected grain yield significantly during both planting dates, with 0.30 m rows recording a significantly greater grain yield compared to 0.60 m rows. The grain yield recorded for the first planting was considerably greater (on average 0.85 t ha^{-1}) compared to the second planting, but the difference between planting dates was slighter than in the 2016/17 season. Interestingly the difference in grain yield for MG 4.5 between planting dates was notably smaller, especially during the 2017/18 season, than that of MG 5 and MG 6. Similar to the 2016/17 season, grain yield was significantly affected by maturity group and row width the most, while plant density only had a significant effect on grain yield during the second planting.

This study's results differ from the findings in chapter 3 and 4 (See Chapter 3.4.7.2 and 4.4.7.2 for discussion). In agreement with this study, Kumagai and Takahashi (2020) reported that delayed planting resulted in a lower grain yield compared to a normal/earlier planting date. Between planting dates there were considerable differences in grain yield, with the first planting date recording on average a 1.6 t ha^{-1} and 0.85 t ha^{-1} greater yield for the 2016/17 and 2017/18 season respectively, compared to the second planting dates. This is in agreement with De Bruin and Pedersen, 2008a who also reported that late planting results in significant yield losses. MG 4.5 and MG 5 recorded the greatest grain yield for the second planting which is in agreement with Salmerón *et al*., (2015) who reported that shorter maturity groups out yielded longer maturity groups when planted late. During the 2017/18 season MG 4.5 recorded similar grain yield for both plating dates which concurs with Salmerón *et al*., (2015) who reported that MG 4 maintained the same yield for all planting dates.

The reason for there being such great differences in grain yield between the two planting dates are simply a shorter growth period for the plants planted at the second planting date, resulting in less optimum temperatures and reduced light interception (Salmerón *et al*., 2015). During the 2016/17 season the second planting date had a 5-week shorter growing period and the 2017/18 season a 3-week shorter growing period compared to the first planting date. Planting date had a great effect on each maturity group's grain yield. During the 2016/17 season, the first planting date (28 October 2016), which is considered to be a normal planting date in the North Eastern Free State, MG 6 recorded the greatest yield, followed by MG 5 and MG 4.5. At this planting date, the growth period/season was long enough for the MG 6 to complete growth and development to produce a maximum yield. Comparing this result for the 2017/18 season with the first plating date (16 November 2017) -which is considered a late planting date- the effect of a shorter growing period/season is evident MG 6 recorded a lower grain yield compared to MG 5. This growing period/season was just too short for the MG 6, while MG 5 could still produce an optimum grain yield. In both the 2016/17 and 2017/18 season, MG 4.5 recorded the lowest grain yield, but still produced satisfactory yields. The second planting dates for both seasons were similar (5 December

2016 and 4 December 2017). During the 2016/17 season, MG 5 recorded by far the greatest grain yield, followed by MG 4.5, with MG 6 recording the lowest grain yield by far. During this season MG 5's growth and development was similar to that of MG 4.5. The number of days to R1 (42 days) and total growth period (112 days) was the same, while the period for R1 to R5 was 21 days longer. This is probably the reason for MG 5 recording a greater yield, due to optimisation of the growing period/season and having a longer period for flowering and pod production. During the 2017/18 season, MG 4.5 recorded the greatest grain yield, with MG 5 and MG 6 recording a lower grain yield by far. Comparing the two seasons, the growth period was similar, but the difference was in rainfall. The 2017/18 season had lower than average rainfall during January and February which affected both MG 5 ad MG 6 negatively. During January MG 4.5 already started with flowering and pod-set, while MG 5 and MG 6 only started in February when it was dryer there than normal, realising lower grain yields.

Plant density had no effect on grain yield for the first planting date during both the 2016/17 and 2017/18 season. However, at the second planting date, plant density affected grain yield significantly. Row width also had a significant effect on grain yield for the second plating date during both the 2016/17 and 2017/18 season. According to these results there are positive responses to increased plant density as well as narrower rows, especially at later planting dates. The reason for this result is possibly due to more limited plant development during late planting dates. This in effect means plants take up a smaller area for growth and development, hence increasing plant density and placing plants closer together, optimising yield potential.

5.5 Summary and conclusion

The interaction effect of maturity group, plant density and row width influenced all parameters significantly, except for the number of days to 50% flower initiation, physiological maturity and the number of seeds per pod. The main effects had a significant effect on each parameter measured, except for the number of seeds per pod.

For the first planting date maturity group was the treatment factor that significantly affected phenological development i.e. number of days to 50% flower initiation (R1), flower initiation to beginning seed-filling (R1-R5), beginning of seed-filling to physiological maturity (R5-R8) and the total growth period. MG 4.5 reached R1 and R8 in the shortest number of days for both cropping seasons, followed by MG 5 and MG 6. The second planting date had similar results, but because of a shorter growing season, each maturity group had a shorter total growing period. This is due to the varietal characteristics of each maturity group, which is controlled by the specific maturity group's genetics and each particular response to photo period. Plant height for the first planting increased significantly with increasing plant density only for the 2016/17 cropping season. The 2017/18 cropping season showed a surprising decrease with increasing plant density. There were also significant differences between maturity groups, with MG 5 and MG 6 recording the highest plant height, significantly higher than MG 4.5, with the lowest plant height for both cropping seasons. The differences in plant height for the different maturity groups are also due to the varietal characteristics of each maturity group. Row width also had a significant effect on plant height, with the 0.60 m rows recording significantly the highest final plant height. The second planting date had similar results but produced considerably lower plant heights. Pod clearance for the first planting date was significantly affected by maturity group, with the highest pod clearance recorded for MG 6, followed by MG 5 and MG 4.5, with markedly significant differences between all three maturity groups for both cropping seasons. Plant density also affected pod clearance significantly for both cropping seasons, with a general increase in pod clearance with increasing plant density. Row width had no significant effect on pod clearance. The second planting date had similar results, producing slightly lower pod clearances, so minute as to warrant exclusion.

The number of pods per plant for the first planting date was significantly affected by plant density, with the number of pods per plant decreasing significantly with increasing plant density. Maturity group also had a significant effect on the number of pods per plant, with MG 6 recording the greatest number of pods per plant for the 2016/17 cropping season, followed by MG 4.5 and MG 5. The 2017/18 cropping season resulted in the opposite occurrences, with MG 4.5 recording the greatest number of pods per plant, followed by MG 5 and MG 6, but with no significance differences. Row width had no significant effect on the number of pods per plant. The second planting date had similar results, while row width affected number of pods per plant significantly with 0.30 m rows recording a greater number of pods per plant compared to 0.60 m rows. Hundred-seed weight for the first planting date was significantly affected by maturity group with different results between both cropping seasons. During the 2016/17 cropping season MG 4.5 recorded the greatest hundred-seed weight, followed by MG 6 and MG 5 with the significantly lowest hundred-seed weight. During the 2017/18 cropping season, MG 6 significantly recorded the greatest hundred-seed weight, followed by MG 5 and MG 4.5, with a significantly lower hundred-seed weight than MG 6. Plant density also had a significant effect on hundred-seed weight which generally decreased with an increase in plant density. For the second planting date, hundred-seed weight was also significantly affected by maturity group and plant density, while row width also affected hundred-seed weight during the second planting date. These results were only for the 2016/17 cropping season, while for the 2017/18 cropping season, hundred-seed weight was not significantly affected by any treatments. The second planting date had a considerably lower hundred-seed weight compared to the first planting date.

Grain yield for the first planting date was influenced significantly by maturity group. MG 6 recorded the significantly greatest grain yield, followed by MG 5 and MG 4.5 for the 2016/17 cropping season, while MG 5 recorded the significantly greatest grain yield, followed by MG 6 and MG 4.5 for the 2017/18 cropping season. There was also a significant difference in grain yield between the row widths, only for the 2016/17 cropping season, but in both seasons the 0.30 m rows recorded the greatest grain yield compared to the 0.60 m rows. At the second planting date, grain yield was significantly affected by maturity group, plant density and row width. The second planting date recorded considerably lower grain yields compared to the first planting date. Within each season, maturity group affected grain yield differently, which was due to rainfall within each season. Grain yield had a tendency to increase with increased plant density. Regarding row width, 0.30 m rows recorded a significant greater grain yield compared to 0.60 m rows during both seasons for the second planting date.

To conclude, maturity group affected all parameters measured for both planting dates. However, maturity group had the greatest effect on physiological development, pod clearance and grain yield. Plant density had the greatest effect on plant height, number of pods per plant and to some extent grain yield. Maturity group and plant density both had a greater effect on hundred-seed weight. Row width had the greatest effect during the second planting, especially on number of pods per plant, hundred-seed weight and grain yield.

Chapter 6

Summary, conclusion and recommendation

In South Africa, soya bean production began increasing from the late 1990 and since 2008 has rapidly increased (DAFF, 2011). The Free State province is the second largest producer of soya beans in South Africa, with the cultivation concentrated in the North Eastern part of the province. The North Eastern Free State has a unique climate, situated in eastern Highveld also known as the cold interior of South Africa. The occurrence of late frost, up until October, and early frost as soon as April, is common, limiting the growing season length. Planting date, maturity group, plant density and row width are well known agronomic inputs that can be adjusted as factors to improve productivity. Research has been done on these agronomic inputs mainly in other countries. However, very little, if any research was done in South Africa, especially in the North Eastern Free State.

The objectives of this study were as follows: a) to evaluate the yield response to different maturity groups, plant densities, row widths, and planting dates; b) to identify the best maturity group, plant density and row width that optimize yield for different planting dates from mid-October to December; c) to identify which maturity group, plant density and row width to plant at certain planting dates in order to reach maximum yield within the North Eastern Free State.

Three trials were conducted on farmers' fields over two seasons (2016/17 and 2017/18). The same maturity groups (MG 4.5, MG 5 and MG 6) were planted at different plant densities, row widths and planting dates at each trial. Phenological development, plant height, pod clearance, number of pods per plant, number of seeds per pod, hundred-seed weight and grain yield were measured. At trial 1 the three maturity groups were planted at four plant densities (200 000, 300 000, 400 000 and 500 000 plants ha^{-1}). Only maturity group had a significant effect on the phenological development. MG 4.5 took the shortest number of days to reach R1 (beginning bloom/flowering) and had the shortest growing length, followed by MG 5 and MG 6. Plant height was affected by both maturity group and plant density. Plant height generally increased with increased plant density. Pod clearance was most affected by maturity group, while the effect of plant density was negligible. Pod clearance increased from MG 4.5 to MG 5 (±11 cm) as well as to MG 6 (±8-10 cm). Number of pods per plant was most affected by plant density, generally decreasing with increased plant density. Number of seeds per pod was not significantly affected by any treatment. Hundred-seed weight was affected only by maturity group, with MG 4.5 recording the greatest hundred-seed weight, followed by MG 5 and MG 6. Grain yield was affected by both maturity group and plant density. Maturity group affected grain yield significantly only during the 2017/18 season with MG 4.5 recording the greatest grain yield, followed by MG 5 and MG 6. However, during the previous season (2016/17), grain yield showed a similar tendency, although not to a significant extent. Plant density affected grain yield only during the 2016/17 season with grain yield increasing with increased plant density.

At trial 2 the three maturity groups were planted at four plant densities (150 000, 200 000, 300 000 and 400 000 plants ha^{-1}) and two row widths (0.38 m and 0.76 m). Similar to trial 1, only maturity group had a significant effect on phenological maturity. MG 4.5 took the shortest number of days to reach R1 (beginning bloom/flowering) and had the shortest growing length, followed by MG 5 and MG 6. Plant height was affected by both maturity group and plant density for both seasons. Plant height generally increased with increased plant density. Row width only had an effect on plant height during the 2016/17 season, with 0.76 m rows recording a greater plant height compared to 0.38 m rows, but this was negligible. Pod clearance was most affected by maturity group and increased from MG 4.5 to MG 5 and MG 6 in a similar manner to trial 1. Plant density only had a significant effect during the 2016/17 season with pod clearance increasing slightly with increased plant density, while row width only had a significant effect during the 2017/18 season with 0.76 m rows recording a slightly higher pod clearance. The effect of plant density and row width on pod clearance was insignificant. Number of pods per plant was most affected by plant density, generally decreasing with increased plant density. Maturity group also had a significant effect on number of pods per plant, but this effect was not as profound. Row width also had an effect on number of pods per plant during the 2017/18 season only, but with no definite trend. Number of seeds per pod was not significantly affected by any treatment. Hundred-seed weight was affected only by row width during the 2016/17 season with 0.76 m rows recording a greater hundred-seed weight compared to that of 0.38 m rows, while during the 2017/18 season only maturity group affected hundred-seed weight with MG 4.5 recording the greatest hundred-seed weight, followed by MG 6 and MG 5. Grain yield was significantly affected by maturity group and plant density only during the 2017/18 season, while significantly affected by row width during both seasons. MG 6 recorded the greatest grain yield, followed by MG 4.5 and MG 5. Grain yield increased slightly with increased plant density while row width had the greatest effect on grain yield. The greatest grain yield was recorded at 0.38 m rows.

At trial 3 the three maturity groups were planted at four plant densities (150 000, 300 000, 400 000 and 600 000 plants ha^{-1}), two row widths (0.30 m and 0.60 m) and at two planting dates (early/normal and late). Only maturity group had a significant effect on the phenological development for both plantings and seasons. MG 4.5 took the shortest number of days to reach R1 (beginning bloom/flowering) and had the shortest growing length, followed by MG 5 and MG 6. Between planting dates of the second planting each maturity group took less days to reach R1 and had a shortened total growth period. For both seasons MG 4.5 took 7 days less, MG 5 took 14 and 21 days less and MG 6 took 14 days less to reach R1, while the total growth period was shorter for MG 4.5 by 21 days, for MG 5 by 28 and 14 days, and MG 6 by 21 and 14 days. Plant height was affected by maturity group, plant density and row width as well as planting date. For the first planting, maturity group had an effect on plant height only during the 2017/18 season, with plant height increasing significantly from MG 4.5 to MG 5 as well as to MG 6. Plant height increased with increased plant density during the 2016/17 season, but surprisingly during the 2017/18 season plant height decreased with increased plant density. In both seasons 0.60 m rows recorded the highest plant heights compared to 0.30 m rows. For the second planting the same trend was observed with plant height increasing from MG 4.5 to MG 5 and MG 6. Plant height increased with increased plant density and 0.60 m rows recorded a higher plant height compared to 0.30 m rows. However, the plant heights for the second planting were considerably shorter for the 2016/17 season (± 30 cm) and only slightly shorter for the 2017/18 season compared to the first planting. Pod clearance was affected by maturity group and plant density during the 2016/17 season, while during the 2017/18 season, pod clearance was affected by maturity group and row width. Pod clearance increased from MG 4.5 to MG 5 as well as to MG 6 for both planting and seasons. For the 2016/17 season, pod clearance increased with increased plant density. Rows 0.60 m apart recorded a higher pod clearance compared to 0.30 m rows only during the second planting of the 2017/18 season. Pod clearance was affected most extensively by maturity group, while the effects of plant density and row width was not as profound. Between planting dates, the first planting date's pod clearances were slightly higher (1 to 2 cm/ ± 12%) during the 2016/17 season only. Planting date did not have a great effect on pod clearance. Number of pods per plant was affected only by plant density for the first planting during both seasons, while maturity group and row width also had an effect for the second planting during both seasons. For both planting dates and seasons, number of pods per plant decreased with increased plant density. For the second planting during both seasons, MG 4.5 recorded by far (40-50% more pods per plant) the greatest number of pods per plant, followed by MG 6, with MG 5 recording the lowest number of pods per plant. Row width also had an effect on number of pods per plant for the second planting with 0.30 m rows recording 10 or 20% more pods per plant compared to 0.60 m rows. Number of seeds per pod was not significantly affected by any treatment. Hundred-seed weight was affected by maturity group and plant density for the first planting during both seasons, while also by row width for the second planting during the 2016/17 season only. For the first planting during the 2016/17 season, MG 4.5 recorded the greatest hundred-seed weight, followed by MG 6, with MG 5 recording significantly the lowest hundred-seed weight, while during the 2017/18 season hundred-seed weight increased from MG 4.5 to MG 5 as well as to MG 6. For the second planting during the 2016/17 season, the greatest hundred-seed weight was recorded for MG 5, followed by MG 6 and MG 4.5. For the first planting, hundred-seed weight decreased with increased plant density for both seasons, while for the second planting hundred-seed weight increased with increased plant density for both seasons. However, only to a significant degree during the 2016/17 season. Row width only had an effect for second planting during the 2016/17 season with 0.60 m rows recording a slightly greater hundred-seed weight compared to 0.30 m rows. Grain yield was affected by maturity group for the first planting during both seasons. During the 2016/17 season, grain yield increased from MG 4.5 to MG 5 as well as to MG 6, while during the 2017/18 season MG 5 recorded the greatest grain yield, followed by MG 6 and MG 4.5. Plant density had no effect on grain yield for the first planting while row width only affected grain yield during the 2016/17 season with 0.30 m rows recording a significantly greater grain yield compared to 0.60 m rows. For the second planting, maturity group, plant density and row width affected grain yield. During the 2016/17 season MG 5 recorded by far the greatest grain yield, followed by MG 4.5, and MG 6 with the lowest grain yield. During the 2017/18 season, MG 4.5 recorded by far the greatest grain yield, followed by MG 5, with MG 6 again recording the lowest grain yield. For both seasons, grain yield increased with increased plant density, while 0.30 m rows recorded a greater grain yield compared to 0.60 m rows.

In conclusion, maturity group had the greatest significant effect on phenological development, plant height and pod clearance. Maturity group also had an effect on hundred-seed weight and grain yield, while number of pods per plant was least affected by maturity group. Maturity group in combination with planting date affected grain yield greatly. Early/normal planting dates generally resulted in an increase in grain yield from MG 4.5 to MG 5, as well as to MG 6, while late planting dates generally resulted in a decrease in grain yield from MG 4.5 to MG 5 and MG 6. Plant density had the greatest effect on plant height and number of pods per plant. With increased plant density, plant height increased significantly, while number of pods decreased significantly. Plant density also had an effect on pod clearance, hundred-seed weight and grain yield. The effect on pod clearance and hundred-seed weight was not as profound, while grain yield increased slightly with increased plant density, especially during late planting dates. Row width had the greatest effect on plant height and grain yield. Plant height generally increased with an increase in row width, while grain yield decreased with an increase in row width. Thus, narrow rows resulted in a greater grain yield compared to wide rows. Row width also affected pod clearance, number of pods per plant and hundred-seed weight, but this was not as profound. Planting date most affected plant height, hundred-seed weight and grain yield, with the second planting recording shorter plants, lower hundred-seed weights and lower grain yields compared to early/normal planting dates.

Recommendations

Recommendations are based on the results of the three trials of different agro-ecologies of the north eastern Free State and are as follows:

- MG 5 and MG 6 must be planted at planting dates no later than 15 November for optimal yields. When planting after 15 November, MG 4.5 is considered the most suitable maturity group for optimal yields. MG 5 could also be considered, while MG 6 is not recommended.
- Increased plant density showed a slight increase in yield. Seed as well as commodity price will ultimately determine planting density. Three hundred thousand (300 000) plants ha^{-1} seems to be the optimum plant density recommendation for all maturity groups and row widths for the north eastern Free Sate, especially during early/normal planting dates.
- For late planting dates, increased plant densities, 300 000 to 400 000 plant ha^{-1}, are recommended to compensate for smaller plants and shorter growing season.
- Narrow row widths are also recommended for optimal yields, especially for late planting dates, to compensate for smaller plants.

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