Effect of plant density on growth and yields of six soybean (Glycine max L. Merril) cultivars grown at three localities in South Africa

GF Braga
Student Number: 25297732

orcid.org/0000-0002-7249-5204

Bachelor – 2005- EDUARDO MONDLANE UNIVERSITY (EMU)

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Supervisor: Prof. F R Kutu
Co-supervisor: Annelie S de Beer

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ABSTRACT

Agronomic field trials were conducted at Potchefstroom, Rustenburg and Bethlehem during the 2013/4 planting season to investigate the effect of plant density on growth and productivity of six commercial soybean cultivars. Treatments consisted of six plant densities (200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants ha^{-1}) planted at three inter-row spacing (90, 75, and 45 cm) for the six different roundup ready soybean cultivars (LS 6240R, PAN1454R, PAN 1654R, PAN 1500R, LS 6164R, and PAN 1614R). The trial at each locality was laid out in a split-split plot arrangement and fitted into a randomized complete block design (RCBD). Growth and phenological data were collected from the trials and data collected were tested for comparable magnitude using Shapiro-Wilk's test for assessment of deviation from the normality. Weighted combined analysis of variance and pair-wise comparisons were also carried out using the Fishers least square means of significant (LSD) test at a probability level of 5%.

Soybean grain yield was significantly affected by plant density, locality x density, locality x cultivar, and density x cultivar interaction effects. Grain yield at Potchefstroom was higher (4 389.5 kg ha^{-1}) than either Rustenburg (3 553.1 kg ha^{-1}) or Bethlehem (3 409.5 kg ha^{-1}). The cultivar that performed the best at Potchefstroom was PAN 1500R (5 820.2 kg ha^{-1}) at a plant density of 400 000 plants ha^{-1} and a row spacing of 45 cm. The protein content of soybean grains was significantly affected by plant density, cultivar variation, locality × density and locality × cultivar interaction effects. Grains harvested from Rustenburg had the highest protein content (44.1%) than either Bethlehem (41.1%) or Potchefstroom (40.9%). The plant density that gave the highest grain protein (44.5%) content was 400 000 plants ha^{-1} at 75 cm row spacing. The cultivar LS 6164R had grain with the highest protein content (45.3%) at Rustenburg. The oil content of soybean grain trial was significantly affected by plant density, cultivar and locality x cultivar interaction effects. Grain harvested from Potchefstroom had the highest oil content (21.0%). The highest seed oil content of 21.9% was obtained in cultivar LS 6240R grain harvested at Potchefstroom while cultivar PAN 1664R at Bethlehem had the least oil content of 19.3%.

Keywords: Oil seed, plant density, protein, row spacing, soybean cultivars, yield

DECLARATION

I, Gabriel Francisco Braga, declare that, this dissertation of the degree Master in Crop Science at the North West University-Mafikeng Campus has not been submitted by me for a degree at any other University.

Gabriel Francisco Braga

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Gabriel Francisco Braga

North West University-Mafikeng Campus

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LIST OF ABBREVIATIONS

ANOVA : Analysis of Variances

ARC : Agriculture Research Council

DF : Degrees of Freedom

GCI : Grain Crops Institute

ISCW : Institute for Soil, Climate and Water

K : Potassium

LS : Link Seed

LSD : Least Significant Difference

MS : Mean Squares

N : Nitrogen

NIR : Spectrometer-Near Infrared

P : Phosphorus

PAN : Pannar

R : Roundup

RCBD : Randomized Complete Block Design

SAS : Statistical Analysis System

STD : Spacing Trial Density

T : Treatment

T-Gr : T- Grouping

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CHAPTER 1

INTRODUCTION

1.1 Background

Soybean (*Glycine max* L. Merril) is cultivated in many countries of the tropics and subtropics (Barnes, 2010). Soybean plants are photosensitive and thus dependent on temperature and day length. Soybean can be consumed as highly nutritious vegetables or grains; and is well-suited to smallholder production under adverse climatic conditions (Shurtleff & Aoyagi, 2013). It is a popular grain and vegetable legume crop that is largely grown in countries like Japan, Korea, China and Taiwan, where consumption is increasing very rapidly (Shurtleff & Aoyagi, 2013). In South Africa, Mpumalanga province produces the largest quantities of soybean representing about 42.7% of the country's total production (Crop Estimates Committee, 2014). In Africa, Egypt was the first country to produce soybean in 1858, followed by Tunisia in 1873 while southern African countries like Zimbabwe (1906), Malawi and Zambia (1910), Sudan (1912), Mozambique (1915), Burundi and Ruanda (1927), Lesotho (1936), and Botswana (1976) came on board later (Shurtleff & Aoyagi, 2013). Other African countries such as Tanzania (1907), Kenya (1909), Nigeria (1910) and Uganda (1913) were also reported to be involved in soybean production. The Cedara Memoirs of 1903 are believed to carry the first report of soybean production in South Africa from seeds imported from China (Mendonça & Carrão-Panizzi, 2003).

The cultivation practices for both vegetable, known as *Edamame* (Japanese name language), and grain soybeans are similar (Liebenberg, 2012). Many constraints associated with soybean production need to be addressed in order to improve the quality of protein and oil (Mack *et al.*, 2005). Soybean has excellent potential for enriching human diet; and it is reported to be a rich source of vitamin A, carbohydrate, protein and iron (Liebenberg, 2012). Globally, soybean seed is described as probably the largest source of vegetable oil and protein as it contains about 40% crude protein and 20% oil (Shurtleff & Aoyagi, 2013).

Plant density is an important factor that affects yield and yield components of legumes such as soybeans (Ayaz *et al.*, 2004). Lower plant density possesses ability to increase the pod number per plant while higher plant density reduces the pod number (Kobata & Kakiuchi, 2004). Soybean cultivar is also an important factor that affects response and adaptability to any agro-ecological and climatic conditions; and consequently, their ability to produce higher yields. A cool environment is considered more suitable for short physiological maturity cultivars while a relatively hotter environment is regarded suitable for long physiological maturity cultivars; with relatively short growing season cultivars possessing lower pod and plant height than long growing season cultivars (Liebenberg, 2012). Hence, promoting soybean production through increasing adaptive research can increase soybean availability in the region. This may help overcome the problem of malnutrition in many poor homes and communities through the provision and growing of better quality and high yielding soybean cultivars in several places (Keatinge *et al.*, 2011). The Centre for Monitoring of Indian Economy in 2012 revealed that the average soybean production was 1 235 kg ha^{-1} from Indian farms and also for many locations in different African countries (Ramesh & Ramprasad, 2014). Today, soybean is becoming the most important crop in the world since it is considered as the most efficient and least costly source of protein and oil (Clemente & Cahoon, 2009). Therefore, there is an urgent need to identify suitable soybean cultivars with excellent growth attributes that increase yield potential and are also adaptable to the various changing soybean growers production practices.

1.2 Problem statement and justification of the study

In South Africa, the most important buyers of soybean are oil-extracting industries, full fat processors, and poultry and pig feed producers. Soybean producers/farmers are, therefore, more interested in optimal seed production in competitive market (Liebenberg, 2012). However, low grain yield and poor yield quality attributes of commercial soybean are key problems that affect South African soybean growers or producers (Mendonça & Carrão-Panizzi, 2003). There are also the constraints around huge inherent variations in the performance of the different locally available cultivars coupled with farmers' use of inappropriate plant population. However, attempts to increase soybean productivity via plant population increase by growers have not been successful in many instances due to competition for light, nutrients and water; and the unintended negative effects of limited plant growth across cropping regions (Mendonça & Carrão-Panizzi, 2003). Furthermore, current available field data on plant density across different regions aimed at addressing the problem of low soybean yield is inadequate considering the continuous release of new varieties by seed companies. Hence, continuous field studies are required to provide insight into the combination of the effect of plant competition within a certain density among the various cultivars including the newly released ones. Although the competition for environmental resources increases at higher plant population, available evidence (Liebenberg, 2012) suggests that it resulted in better weed control and increased productivity. Nevertheless, the low or limited knowledge on the potential impact of light interception on commercial soybean yield is a problem for South African farmers. Among the strategies for achieving higher crop yields is increased plant population that seeks to optimize light interception through complete coverage of the soil. This can be achieved through the manipulation of sowing density and spatial arrangement to promote rapid leaf expansion (Mendonça and Carrão-Piazinni, 2004). Findings from this study will provide quantitative information that will increase knowledge on important agronomic practices that will promote increased soybean production in the country.

1.3 Research aim and objectives

1.3.1 Aim

The study aims to assess the influence of plant density on growth and productivity of six soybean cultivars in three different localities in South Africa.

1.3.2 Specific objectives

i - Assess the growth attributes of six commercial soybean cultivars at three different localities.

ii - Analyze the grain yield and yield attributes of six commercial soybean cultivars at three different locations.

1.4 Research hypotheses

i - The potential growth ability of different soybean cultivars under appropriate density will be similar across all localities.

ii - The six soybean cultivars will have comparable grain yields across all planting densities and localities.

iii - The most appropriate planting density for the six soybean cultivars is unknown.

1.5 Significance of the Study

The development of excellent and effective production technology such as improved agronomic practice is crucial to increase soybean grain yields and availability. The production of good and high quality soybean grain yield by farmers for local and international markets at fairly competitive and profitable market price is therefore paramount. Thus, findings from this study could stimulate several added opportunities and spinoffs for farmers through increase commercial soybean production and productivity. Also, findings from this study could increase the number of soybean farmers (including smallholders) thereby increasing South Africa and global soybean production.

CHAPTER 2

LITERATURE REVIEW

2.1 Origin, distribution and economic importance of soybean

Soybeans are indigenous to Manchuria, China, and it is considered to be one of the five oldest cultivated crops utilized by the Chinese as a source of food before 2500 B.C. (Liebenberg, 2012). However, it was only discovered by the Western world as a source of oil and protein in the 19th century (Mendonça & Carrão-Panizzi, 2003). In the past 30 years, global soybean production has increased to more than 100 million metric tons; with about 51% of this volume produced in the USA, 20% in Brazil, 10% in Argentina and 10% in China (DAFF, 2015). According to USDA (2016), the 2015 global soybean production was 324.2 million tons representing 5% more than the 2014 production volume. The report suggests that USA produced the largest amount of about 103.4 million tons followed by Brazil (103.0 millions of tons), Argentina (57.0 millions of tons), China (12.2 millions of tons), India (11.7 millions of tons) and South Africa with only 0.8 million tons. The first South African soybean breeding line with good adaptation and resistance to shattering was released at the Potchefstroom research station in the early fifties under the name Geduld; and this remained the most important variety up to the early 80's (DAFF, 2014). Initially, soybean production in South Africa was limited to Bapsfontein and the Northerly Lowveld areas but has gradually become important in rotation with wheat in irrigation areas (Mendonça & Carrão-Panizzi, 2003).

Soybean plays a very important role in South Africa economy with more money often spent on the importation of soybean grains and cakes mostly from within SADC region, Argentina and South America, due to low yield. In 2012, soybeans were produced on an estimated 2.2 per cent of the world's agricultural land, with a total production of 253.1 million metric tons (FAO, 2013). Recent projections of global soybean production for 2016/17 is around 323.7 million metric tons while in 2015, the production was 313.26 million tons representing an increase of 10.44 million tons, approximately 3.33% (USDA, 2016). Nevertheless, the amount spent on importation in South Africa has declined significantly between 2008 and 2011 mainly as a result of an increase in production volumes (Mogala, 2012). The sale of soybean seed in South Africa by the grain legume market has grown over the past 10 years. According to SANSOR (2014), the sales of soybean seed amounted to R 3.6 million with 52% being sales of genetically modified soybean seed.

Soybean oil is used industrially in the manufacturing of paints, linoleum, oilcloth, printing inks, soap, insecticides, and disinfectants. Lecithin phospholipids are obtained as a by- product of soybean oil and are used as a wetting and stabilizing agent in the food, cosmetic, pharmaceutical leather, paint, plastic, soap, and detergent industries (Liebenberg, 2012). Soybean meal and protein are reportedly used in the manufacturing of waterproofing, synthetic fibre, adhesives, textile sizing, fire-fighting foam and for many other purposes while soybean plant straw is also considered to be useful for making papers that are stiffer than those made from wheat straw (Liebenberg, 2012).

Soybean is among the major industrial and food crops grown in every continent; and can be successfully grown in many areas with little agricultural inputs. Its production has expanded in the world as a result of its nutritive and economic importance as well as its diverse usage. It is also a prime source of vegetable oil in the international market whose production is expected to increase as more farmers become aware of the potential of the crop, not only for cash or food but also for soil fertility improvement and *Striga* control (Dugje *et al.*, 2009). Research results also suggest that the soybean market is growing fast with opportunities for improving the income of farmers and many companies that are involved in the processing of soybean grains (Dugje *et al.*, 2009).

2.2 Botanical classification of soybean

Soybean like belongs to the large botanical family of leguminosae (Table 2.1) that includes some 500 genera and more than 12000 species in the subfamily Papilionideae. All food legumes can be divided into two types, namely; oilseeds and pulses; with soybeans being classified as oilseed crops (Mendonça and Carrão-Panizzi, 2003). The popular name of soybean has, however, changed over the past decade mainly due to the confusion that existed in the scientific names and the taxonomy of the plant as shown in the classification in Table 2.1.

Table 2.1: The scientific classification of soybean

Kingdom: Plantae	Subfamily: Faboideae
(unranked): Angiosperms	Genus: *Glycine*
(unranked): Eudicots	Species: G. max
(unranked): Rosids	Binomial name
Order: Fabales	*Glycine max* L merril
Family: Fabaceae	The common name is Soybean

Source: Mendonça and Carrão-Panizzi (2003).

2.3 Soybean production in South Africa

Soybean is mainly grown in six South African provinces (Appendix 1) namely Mpumalanga, Free State, North-West, KwaZulu-Natal, Limpopo and Gauteng (Table 2.2). Out of the six provinces, Mpumalanga Province is the largest producer accounting for 42.7% of the total quantities of soybean grains produced followed by Free State (31.8%), KwaZulu-Natal (10.5%), Limpopo (6.8%), and Gauteng (4.3%) while North-West province only accounts for approximately 2.9% (DAFF, 2014). Soybean production in South Africa during the 2013/14 production season was 832 350 tons from 502 900 ha at an average of 1.7 t ha^{-1} (DAFF, 2015). The average soybean grain yield under dry-land conditions can vary from 2 to 3 t ha^{-1} but the yield potential under irrigation can range between 3.5 and 5.5 t ha^{-1} when planted in November using good quality seeds (DAFF, 2010). It is often preferred that soybean is grown in rotation with maize because it increases the yield of the subsequent cereal crop up to an average of 12% due to nitrogen fixation (Frankow & Dahlin, 2013).

Commercial soybean are largely produced in Mpumalanga (304 500 tons) followed by Free State (281 400 tons) province while in the North-West province, production has increased from 22 750 tons in 2013 to 28 800 tons in 2014 (DAFF, 2015). This increase has been attributed to farmers planting good quality seeds and the right cultivars with high percent germination coupled with the use of the right planting density leading to yield increases from 1.03 to 1.8 t ha^{-1} (DAFF, 2015). Recent research results have shown significant grain yield increases at narrower row spacing from the traditional 91 cm used by majority of soybean producers to 38 - 50 cm (Grain SA, 2015). Plant population in 50 cm rows is between 400 000 and 500 000 plants ha^{-1} depending on soil type (Grain SA, 2015). In South Africa, more than 80% of the soybean grown is Roundup Ready® cultivars that are obtained from various registered seed companies. Decisions on cultivar choice by producers are often based on such characteristics as growth habit, shattering, pod clearance, and resistance to pest, diseases and chemicals (Smit, 2000). However, soybean cultivar TGX 1740-2F (SB19) grown in western Kenya with minimum of 18.3°C to a maximum of 35.8°C has numerous advantages over the conventional cultivars. These include its early maturity ability, promiscuity in nitrogen fixation, and increase in yields despite the reduction in the nodulation upon the application of nitrogen. In South Africa, such cultivar can be grown in places like Potchefstroom and Bethlehem where temperature conditions similar to those in Kenya exist (Andric *et al.*, 2012).

Table 2.2 - Major soybean production areas in six South African provinces

Province	District	Towns
Mpumalanga	GertSibande	Morgenzon, Volkrust, Piet Retief, Perdekop
	Nkangala	Ermelo
	Mankaligwa	Secunda
Free State	Thabo Mofutsanyane	Bethlehem, Warden
	FezileDabi	Villiers, Vrede
Kwa-Zulu Natal	Umgungundlovu	Greytown
	Amajuba	Normandien
	Zululand	Pongola, Vryheid
	UMzinyathi	Dundee
	eThekwini	Winterton, Bergville
Limpopo	Waterberg	Koedoeskop, Naboomspruit
	Sekhukhune	Groblersdal, Marble Hall
North West	Ngaka Modiri Malema	Mafikeng, Delareyville, Lichtenberg, Zeerust
	Dr. Kenneth Kaunda	Potchefstroom Ventersdorp, Klerksdorp
	Bojanala	Rustenburg, Moretele, Koster, Brits
Gauteng	Metsweding	Bapsfontein, Bronkorspruit
	Sedibeng	Heidelberg/Nigel

Source: DAFF (2014)

2.4 Soybean pests and diseases and their management

The development and spread of diseases and pests are often promoted by three prerequisites namely; the presence of causative organism (bacteria, fungus, virus, insect or nematode), a suitable host plant, and a suitable conditions created by climatic factors or cultivation practices (Liebenberg, 2012). Various pests and diseases that affect soybeans are abound. They are often controlled using a number of good cultivation practices such as planting of diseases-free and high yielding seeds, crop rotation, biological control, planting of resistant cultivars and chemical control. In general, the problem of huge yield losses and low grain quality on commercial soybean fields in South Africa are caused by different pests and diseases. Variable percentages of grain yield reduction due to the incidences of pest and diseases during soybean production have been reported. Crop damages during vegetative stage, pod fill stage, and pod-fill to maturity stage cause 30%, 15%, and 25% of seed yield losses, respectively (OMAFRA 2016). The various soybean diseases recorded on soybean fields in South Africa include bacterial diseases (blight and chlorosis); fungal diseases (Seed rot, Charcoal rot, Fusarium pod and root rots, Phomopsis seed rot, Pod and stem blight, Pythium seed decay and root rot, Sclerotinia stem rot, Alternaria leaf spot, brown spot, downy mildew, Asian soybean rust); and viral diseases (soybean mosaic virus, soybean rhabdovirus) while insect damage includes African bollworm, Plusialooper and green vegetable bug (Liebenberg, 2012). Sclerotinia stem rot is considered as the most prevalent disease on commercial soybean fields in South Africa affecting stems, leaves, pods and seeds (Liebenberg, 2012). *Sclerotinias clerotiorum,* also known as cotton rot, watery soft rot, stem rot, drop, crown rot or blossom blight (Agrios, 2005), is a pathogenic fungus that causes significant crop damage by impacting on the light and moisture conditions between rows (Pernezny *et al.*, 2003).

2.5 Impact of planting population on soybean growth and productivity

Seed is one of the most expensive input costs for soybean growers; hence, planting the right amount of seed is crucial to minimizing input costs, increasing profitability through appropriate plant population and row spacing (Appendix 2). High plant population has been reported to promote plant competition and possible lodging while low plant population wastes growing space thereby lowering yield (Robinson & Conley, 2014). Nevertheless, high plant population has been reported to promote quicker canopy closure (Hanna *et al.*, 2007), greater light interception and lower weed competition (Hanna *et al.*, 2007). Thus, high plant population has been reported to result in decreased amount of light captured by each plant (Appendix 3), increased competition for nutrients and water that ultimately limit each plant's growth, and add to seed costs (Robinson & Conley, 2014). Furthermore, high plant densities have been reported to reduce nodulation in soybean crop due to limitation of native soil rhizobia, which could adversely affect productivity and seed yield (Gamini *et al.,* 2000). Low plant population on the other hand has been reported to increase the plasticity of soybean through increased leaf area of individual plant, which allows for greater sunlight capture leading to production of more branches and pods; and also offers competitive yields (Conley & Santini, 2007; Robinson & Conley, 2014). It is, therefore, important for soybean growers to pay attention to seeding rates and plant population in order to maximize grain yield and minimize the costs of all field operations. Consequently, information on optimal seeding rates and plant populations for soybean growers has been reported to significantly reduce input costs and improve profitability (Oplinger & Philbrook, 2014).

2.6 Impact of cultivar variation on soybean growth and productivity

The ARC-Grain Crops Institute (ARC-GCI), Potchefstroom, imports germplasm of different soybean cultivars from USA, Europe (Denmark, Germany, and Netherlands), Japan, Australia and New Zealand, as well as Uruguay in South America (SANSOR, 2014). These are then grown in different growing conditions in South Africa with improvement in their potential and the seeds are sold, not only in South African market, but also exported to other African countries such as Angola, DRC, Kenya, Malawi, Mozambique, Senegal, Sudan, Tanzania, Zambia, and Zimbabwe; as well as in Asia (Pakistan, Turkey); South America (Argentina, Uruguay) and Europe (France), (ARC, 2013). A number of promising soybean cultivars are currently being evaluated and promoted for commercial production in South Africa by ARC-GCI Potchefstroom for different agro-ecology areas. They include LS 6444 R, PAN 1454 R, LS 6146 R, LS 6248 R, PAN 1583 R, PHB 95 Y 20 R, PAN 1666 R, PAN 1664 R, LS 6164 R, LS 6161 R, LS 6453 R, PAN 1500 R, LS 6261 R, and PAN 1614 R. Results of such evaluation revealed that localities and cultivar interaction significantly affected soybean yield; while grain yield was highest with LS 6161 R in the warm, PAN 1500 R in cool and LS 6261 R in the moderate temperature places (ARC, 2015). An earlier study revealed a direct relationship between environment and cultivars or genotypes with a significant (25%) yield loss (McLaren, 2008).

Soybean cultivars are genetically differentiated in terms of their growth habit and are accordingly grouped as determinate or indeterminate, long or early physiological maturity. Other soybean cultivars can be sensitive to soil drying that can exert important effects on growth and production (Shimada *et al.*, 2013). Soybeans with indeterminate growth habit continue to grow as the plant produces flowers and pods while growth stops in cultivars with a determinate growth habit and the growing tip ends in a pod bearing raceme hence often recommended under irrigation (Yamada *et al.,* 2012). In terms of yield, the number of seeds per pod and seed weights is larger in indeterminate soybean cultivars than in determinate cultivars while the number of seeds per plant and the number of pods per plant of indeterminate cultivars were similarly greater than those of the determinate cultivars in early maturation on farmers field (Kato *et al.*, 2015). These yield characteristic are significantly influenced by environmental variation with higher yields under moderate than cool and hot temperatures. However, yields were not significantly influence by soil types and farmers practices under cool temperature (Cober & Morrison, 2010). Soybeans with an indeterminate growth habit flower over a longer period and are reportedly better able to withstand losses due to drought and high temperatures during the flowering stage. As a result, they represent a better choice under moisture stress conditions during early summer. On the other hand, cultivars with relatively short growing season have lower pod and plant height than long growing season cultivars (Liebenberg, 2012).

2.7 Impact of inoculation and fertilizer application on soybean performance

Inoculants are biological substances containing bacteria that are added and/or mixed with seeds either in solid form as slurry (paste) or liquid form on seed rows during the sowing process, so as to improve the atmospheric nitrogen fixation process of leguminous plants (Rampim *et al.,* 2015). Inoculants are often used on commercial farmers' fields to improve crop performance and seed yield at higher planting density under good agro-climatic conditions (Gamini *et al.,* 2000). However, the selection of appropriate strain of nitrogen fixing bacteria in an inoculant is crucial for ensuring good nodulation and higher yields (Balesevic *et al.,* 2011). A study carried out on five farmer's fields in dry zone areas of Sri Lanka (Gamini *et al.,* 2000) showed that inoculated and fertilized soybean crop perform better than unfertilized and uninoculated crop grown at low planting density. The findings from this study further revealed that high plant density reduced plant growth, number of nodules formed and also negatively affected seed yield of soybean. Fertilizer application and inoculation did not increase soybean performance at higher planting density.

Furthermore, results of a field experiment conducted in Southern Spain on the impact of two different inoculants (*Sinorhizobium* and *Bradyhrizobium japonicum*) at four doses (10^4, 10^5, 10^6 and 10^7 rhizobia/seed) in soybean plots revealed significantly higher seed yield in inoculated plants than those without inoculant (Albareda *et al.*, 2009). Their results also revealed increment in nodule dry weight, seed yield and N content when the dose of rhizobia per seed increased from 10^4 to 10^7. An earlier study on the effects of different N rates (0, 30, 60, 90 kg N/ha) on soybean cultivar inoculated with microbial fertilizer (Mrkovacki *et al.*, 2008) revealed that the 60 kg N/ha treatment produced the largest mass and length of aboveground plant parts at the flowering stage. The largest mass, N content and nodule number were recorded in the 30 kg N/ha treatment. The study further showed that the largest pod, grain mass, N content, grain number as well as yield were produced by inoculated but unfertilized plants suggesting that soybean can be successfully grown without N application but with the use of inoculants. Also, research evidences abound which suggest that soybean seed yield and yield stability can be improved by appropriate rhizobia inoculation and fertilizer management in the field. A study conducted by Clayton *et al.* (2004) in a region of Western Canada revealed that soil-applied inoculant resulted in 15, 18, 9 and 0% higher pea biomass yield at the flat pod stage than seed-applied inoculant at 0, 20, 40 and 80 kg N ha^{-1}, respectively. Soil-applied inoculant also resulted in 12% and 15% increases in seed protein concentration more than the seed-applied inoculant and un-inoculated pea, respectively.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of study sites

The trial was planted on experimental plots at the research facilities of Field Crops Division of Agricultural Research Council (ARC) located at Potchefstroom and Rustenburg in the North West Province, and at Bethlehem in the Free State Province. The three sites differed markedly in terms of their climatic conditions and geographical description (Table 3.1). The climate at Rustenburg and Potchefstroom is described as warm and moderate, respectively while Bethlehem zone has a cool climate. The growth development of plants, especially legumes, depends on the climate of an area, with some cultivars better suited for specific environments (Appendix 4).

Table 3.1: - Climatic and geographic information of the three trial sites

	Potchefstroom	Rustenburg	Bethlehem
Mean annual rainfall	622.2 mm	663mm	695mm
Mean daily summer temperature	24°C	25.2°C	18.6°C
Longitude	27°06′12″E	27°15′E	28°14′S
Altitude	1349m	1156m	1630m
Latitude	26°42′54″S	25°40′S	28°18′E

3.2 Description of the experiment, treatments, research design and layout

The experiment was conducted during 2013/14 summer cropping season. The trial at each locality comprised of three treatment factors that were laid out in a split-split plot arrangement fitted into a randomized complete block design (RCBD) with two replications. Treatment factors evaluated consisted of 3 different row spacing (90, 75 & 45 cm), 6 plant densities (200 000, 250 000, 300 000, 350 000, 400 000 & 450 000 plant ha^{-1}) and 6 commercial soybean cultivars (LS 6240R, PAN 1454R, PAN 1654R, PAN 1500R, LS 6164R, PAN 1614R). The six soybean cultivars were herein designated V1, V2, V3, V4, V5 and V6, respectively (Appendix 5). The main plot (18 m^2) was row spacing, while planting density and soybean cultivars constituted the sub-plot (15 m^2) and subplot (9 m^2) treatments, respectively. Although the three localities differ markedly in terms of temperature and rainfall distribution, sowing of seeds across the three sites was done within the same week after sufficient rain had been obtained for planting in order to minimise variation in planting time. The six round-up ready

(R) soybean cultivars used in this trial belong to three different maturity groups namely early maturing (LS 6240R, PAN 1454R); medium maturing (PAN 1664R, PAN 1500R) and late maturing (LS 6164R, PAN 1614R).

3.3 Soil sampling and analysis

A representative surface (0-20 cm depth) soil sample was obtained through random sample collection from each experimental site using soil auger prior to commencement of the trial. The soil samples were subjected to detailed physical and chemical characterization following standard procedures at the Soil Analytical Laboratory of ARC-Rustenburg. The textural parameters (sand, silt and clay) were determined through hydrometer method, the organic carbon content was determined using Walkey-Black method, pH was measured with a pH meter using buffer solution 4 and 7, while mineral nitrogen (nitrate and ammonium N) were determined using auto analyzer following extraction with a 0.1N potassium sulphate solution. Bray 1 extraction method was used to determine available P, 0.1N ammonium acetate extraction method was used to extract K, Ca, Mg, and Na and the concentration measured using atomic absorption spectrometer while conductivity meter was used to measure the electrical conductivity of each sample. Cation exchange capacity was estimated as effective cation exchange capacity (ECEC) through the summation of exchangeable cations and extractable acidity. The summary of analytical results of the representative samples collected from the trial sites are shown in Table 3.2, which were used to make appropriate fertilizer application.

3.4 Seeding

The density of seeding or the number of plants per unit area is a result of the combination of row spacing and number of plants per row while the seeding depth varied according to soil type. In general, seeding depths of 2-4 cm for clay soils and 5-6 cm for sandy soils recommended for legumes (Smit, 2000) were used in this study. Therefore, the various rows spacing that were used during seed sowing to achieve the desired calculated population/density of 200 000 plant ha^{-1}, 250 000 plant ha^{-1}, 300 000 plant ha^{-1}, 350 000 plant ha^{-1}, 400 000 plant ha^{-1} and 450 000 plant ha^{-1} were 90 cm, 75 cm and 45 cm between rows, respectively. However, the choice of intra-row ranged from 2.4 cm to 8.7 cm depending on the targeted plant density within each plot. There were 4 planted rows for each planting density and 18 different combinations of planting densities emanating from variable intra-row spacing and the 3 main inter-row spacing (Appendix 6).

Table 3.2: Some analytical data of the surface (0-20 cm) soil at Potchefstroom, Rustenburg and Bethlehem prior to field trial establishment in 2013/14 planting season

Soil properties		Potchefstroom	Rustenburg	Bethlehem
Sand	(%)	48.7	43.2	72.6
Silt	(%)	17.3	0.8	11.4
Clay	(%)	34	56	16
Textural class		Sandy clay loam	Clay	Sandy loam
% Organic C		0.82	0.20	0.43
pH (H_2O)		6.86	7.89	6.73
Mineral N	($mg\ kg^{-1}$)	20.64	16.76	13.20
P	($mg\ kg^{-1}$)	16.44	14.86	13.38
K	($mg\ kg^{-1}$)	150	243	164
Ca	($mg\ kg^{-1}$)	1270	6440	738
Mg	($mg\ kg^{-1}$)	548	2080	369
Na	($mg\ kg^{-1}$)	45	40	58
ECEC cmol (+) kg^{-1}		11.46	50.19	7.89

3.5 Fertilizer application

Fertilizer application across the three fields was based on the results of soil test. The levels of K in fields were adequate and generally above the critical level defined for soybean by FSSA (2007). Hence, only N and P fertilizers were applied using a tractor at planting time at 18 kg P ha^{-1} and 20 kg N ha^{-1} for Potchefstroom, 20 kg P ha^{-1} and 24 kg N ha^{-1} for Rustenburg and 21 kg P ha^{-1} and 27 kg N ha^{-1} for Bethlehem.

3.6 Seed inoculation process

Bradyrhizobium japonicum WB 74 inoculant, acquired from Stimuli Plant® [Potchefstroom], was used to inoculate the soybean seeds. One sachet of the inoculant containing approximately 125 000 000 living cells was used to inoculate 50 kg of seeds of each cultivar that was planted in the trial. The inoculant was mixed with water in a proportion of 500 gram of inoculant to 1 000 litres of water and applied by tractor by spraying on the seeds at-planting time.

3.7 Data collected

3.7.1 Percentage germination count

The number of days to 50% and 100% germination per plot were-recorded after planting. The number of plants was counted in two rows at one week after plant emergence; and data obtained was used to estimate the germination percentage.

3.7.2 Duration to flowering

The duration to 50% flowering was recorded as the date when at least one flower per plant was observed in half of the total plants in a plot. Hence, weekly field visits were conducted for this purpose starting from 30 days after planting until all the cultivars flowered.

3.7.3 Physiological maturity

Duration to physiological maturity (PM) was recorded and was defined as the time it took for 50% of the pods in each plot to appear yellow or brown.

3.7.4 Harvest maturity

Harvesting commenced when 95% of the pods were dry. At this point most of the leaves had been shed, moisture content of the seed was below 15%; but while the stems were still pliable.

3.7.5 Pod clearance

Pod clearance was measured with a meter ruler from the soil surface until the first pod at maturity growth stage in three plants selected aleatory per plot. The importance of this parameter relates to mechanization during crop harvest and assists greatly in the design of machineries and farmers' selection appropriate harvesting equipment.

3.7.6 Plant height

The height of soybean plants in each plot was measured with ruler from the soil surface to the growing point during harvesting. Plant height was taken on three randomly selected plants in each plot at maturity stage.

3.7.7 Lodging

The number of plants that lodged in a plot was counted, recorded and expressed as a percentage of the total number of plants in each plot, the count of plants lodged was done at physiological maturity stage. Lodging brings about yield losses and also reduce grain quality since the crop will not sufficiently mature before harvesting.

3.7.8 Plant population counts at harvest

All plants harvested from each plot in the two rows were counted and recorded, and subsequently used to estimate the population count obtained at harvest.

3.7.9 Grain yield and yield attributes

All mature dried pods from the two middle rows were manually harvested, threshed and weighed after cleaning to estimate grain yield. The final yield per hectare was estimated from the grain yield and data on plant population count obtained from within the two rows from each plot after correction for moisture content across all cultivars, the percentage moisture content chosen for final grain yield calculation was 12.5%. Soybean harvesting was accomplished when seed moisture content is within the recommended range of 15-18% in order to minimize field deterioration (Peske *et al.,* 2014).

3.7.10 Percent seed protein, oil and moisture content

The protein, oil and moisture content of the seeds from each plot were determined using Near Infrared - NIR spectrometer equipment (Infratec 1241 Analyzer serial NO: 12410942 110-120 / 220-240 v part No: 10008285) as shown in Appendix 7. These parameters are important for storage and constitute key seed quality parameters to both growers and end users.

3.8 Statistical analysis

All growth and yield data generated from the trials were subjected to analysis of variance (ANOVA) and using SAS 9.2 statistical software (SAS, 1999). Significant effects of treatment means were compared using Least Significant Differences (LSD) test at the 5% level of significance. All data for the six soybean cultivars across the three locations were tested for comparable magnitude through a weighted combined ANOVA. Shapiro-Wilk's test (1965) was also performed on the standardised residuals to test for deviation from normality.

CHAPTER 4

RESULTS

4.1 ANOVA significance levels of the different treatments and their interaction effects on measured variables

A total of thirteenth different growth and yield related parameters were taken into consideration that include percentage of seedling emergence; plant height, height of pod, lodging percentage, plant population at harvest, 100-seed weight, grain yield; and percent seed moisture, protein and oil contents. These parameters exerted strong influence on soybean yields. Table 4.1 below shows the analysis of variance (ANOVA) of treatments and their interaction effects on all measured parameters. The results revealed that except for the flowering days (Flow), physiological maturity days (PhM), harvest maturity days (HaM), percentage of plant lodged (Lod), hundred seed weight (HSW) and percent seed moisture (SM) content, all measured parameters were significantly ($p<0.05$) affected by plant density. Similarly, all measured parameters were significantly ($p<0.05$) affected by cultivar variation except percentage plant lodged and grain yield while all measured variables across the three localities differed significantly ($p<0.001$) except the percentage of plant lodged. The interaction between locality and density exerted a very highly significant ($p <0.001$) effect on the percent plant emergence, plant population, grain yield and seed protein content while all the measured parameters except flowering days, physiological maturity days, harvest maturity days, percentage of plant lodged and plant population were significantly ($p<0.001$) affected by locality and cultivar interaction. Density and cultivar interaction exerted a significant ($p< 0.05$) effect on plant height and grain yield (Appendix 8-12).

Table 4.1: Results of p-values for ANOVA of measured growth parameters, yield and yield attributes, and seed qualities of the soybean cultivars across the three localities

Sources of variation	E	H	PdC	Flow	PhM	HaM	Lod	NP	HSW	SM	Y	P	O
Density	$<0.0001^{***}$	0.0002^{***}	0.02^{*}	0.09^{ns}	1.00^{ns}	1.00^{ns}	0.84^{ns}	$<0.0001^{***}$	0.10^{ns}	0.35^{ns}	$<0.0001^{***}$	$<0.0003^{***}$	0.0003^{***}
Cultivar	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	0.48^{ns}	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0007^{***}$	0.43^{ns}	$<0.0001^{***}$	$<0.0001^{***}$
Locality	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	0.32^{ns}	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$
Locality*Density	$<0.0001^{***}$	0.21^{ns}	0.38^{ns}	0.13^{ns}	1.00^{ns}	1.00^{ns}	0.92^{ns}	0.0003^{***}	0.14^{ns}	0.46^{ns}	$<0.0001^{***}$	$<0.0001^{***}$	0.27^{ns}
Locality*Cultivar	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	0.24^{ns}	0.28^{ns}	0.075^{ns}	0.10^{ns}	0.14^{ns}	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$
Density*Cultivar	0.08^{ns}	0.033^{*}	0.14^{ns}	0.89^{ns}	1.00^{ns}	1.00^{ns}	0.070^{ns}	0.063^{ns}	0.068^{ns}	0.24^{ns}	0.043^{*}	0.061^{ns}	0.49^{ns}

Percent emergence (E), Plant height (H), Pod clearance (PdC), Days to flowering (Flow), Days to physiological maturity (PhM), duration to harvest maturity (HaM), Percentage of plants lodging (Lod), Plant population at harvest (NP), 100–Seeds Weight (HSW), Seed Moisture (SM), Grain Yield (Y), Protein Content (P) and Oil Content (O). Note that ns denotes not significant, *, ** and *** denotes significant at the 5%, 1% and 0.1% probability levels, respectively.

4.2 Treatments effect on measured growth parameters

4.2.1 Variation in percent seedling emergence at each trial locality

The highest percent mean seedling emergence (76.9%) across all treatments was obtained at Rustenburg while the least emergence (57.4%) was obtained at Bethlehem as shown in the figure 2a below.

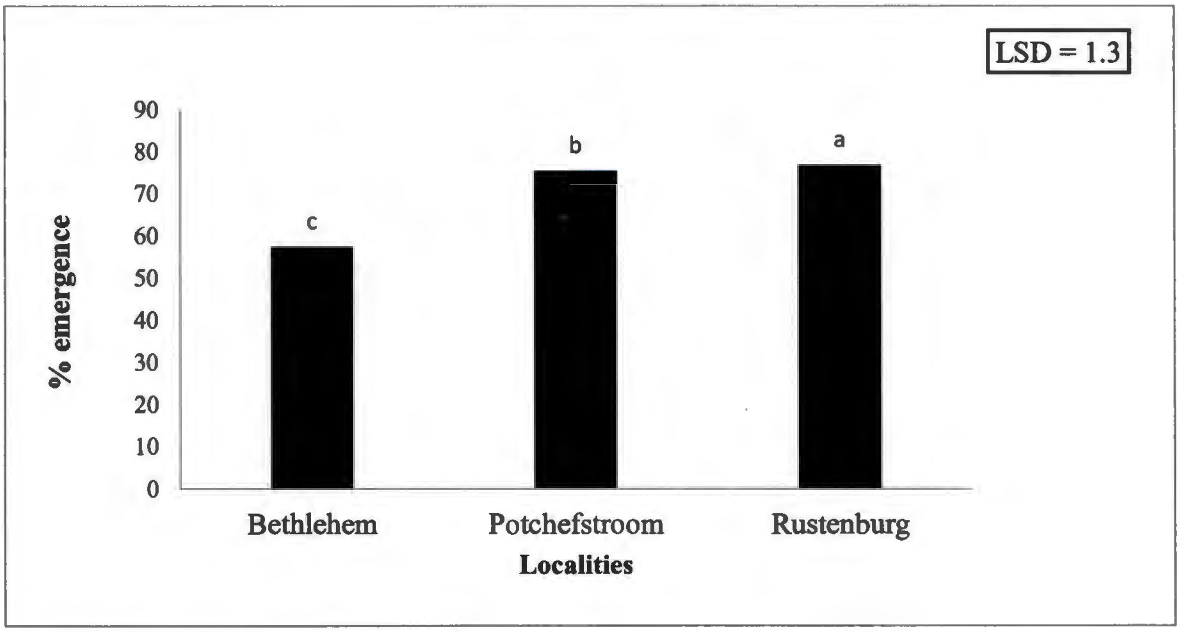

Figure 2a: Percent seedling emergence at each of the three localities

4.2.2 Variation in percent seedling emergence for the different planting densities

Soybean density of 300 000 plants ha^{-1} with seeds sown at 45cm inter-row spacing had the highest mean emergence of 73.9% across the three locations while planting density of 250 000 plants ha^{-1} with seeds sown at 75 cm inter-row spacing had the lowest mean seedling emergence of 62.5% (Figure 2b).

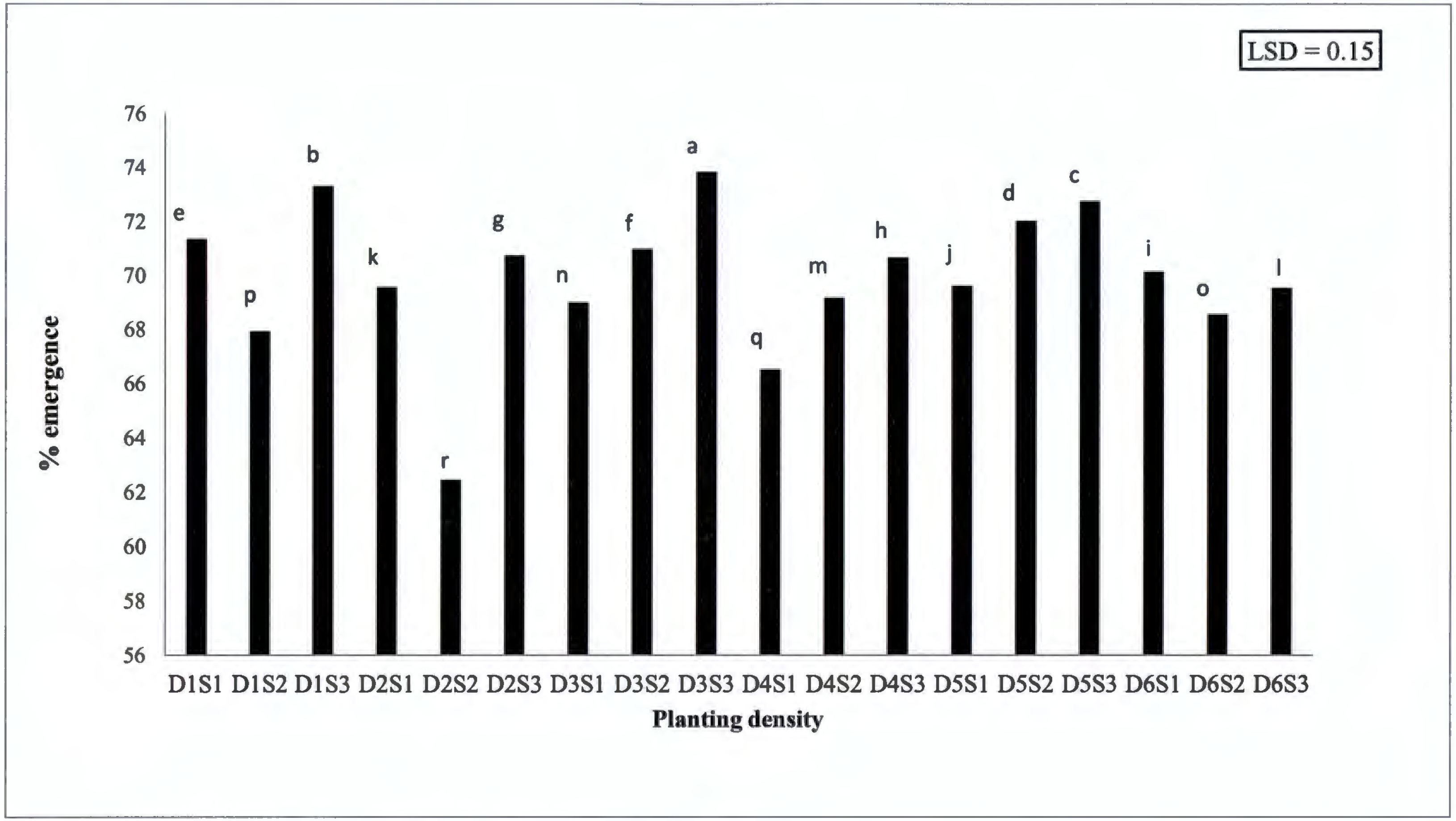

Figure 2b: Percent seedling emergence of the different planting densities

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.2.3 Variation in percent seedling emergence for the different soybean cultivars

The percent seedling emergence (76.8%) across all treatments was highest with soybean cultivar PAN 1500R while LS 6240R had the lowest emergence (55.7%) as shown in Figure 2c.

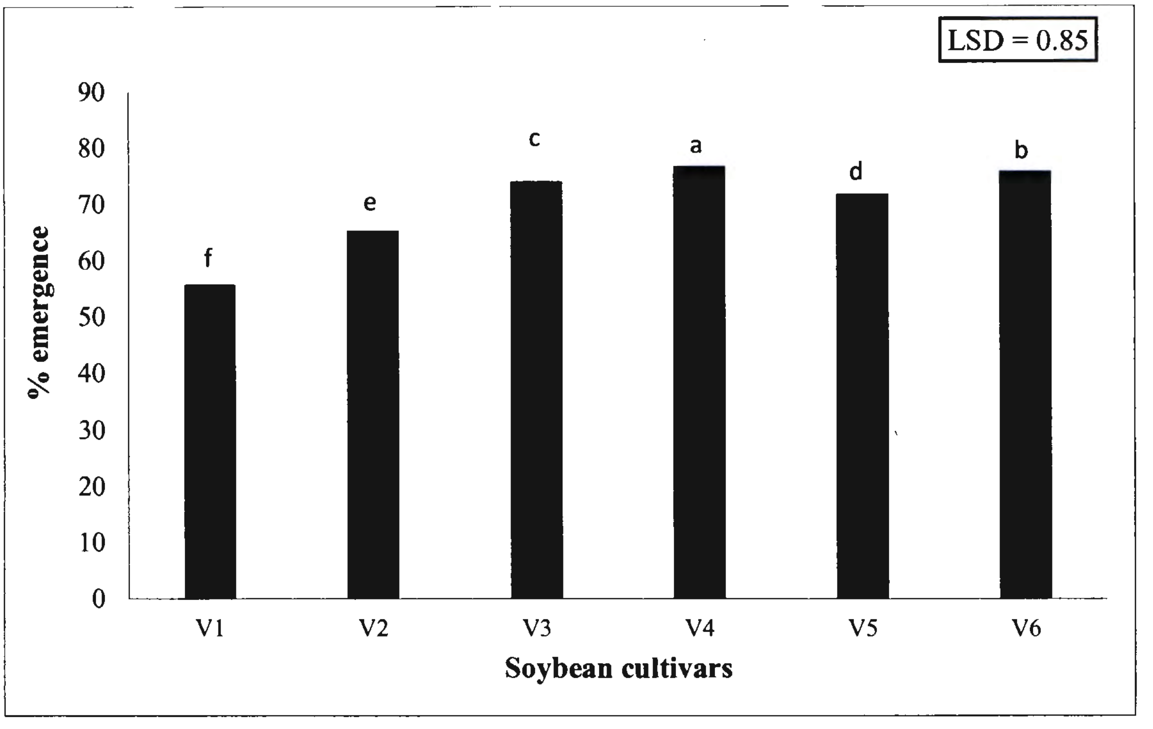

Figure 2c: Percent seedling emergence for the different soybean cultivars
V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.2.4 Variation in pod clearance at each trial locality

Pod clearance is very important for auto-combine (machine) adjustment during harvesting. Pods that are too close to the ground surface often have poor quality as they are easily predisposed to rot. Soybean plants at Bethlehem had the highest mean pod clearance of 10.0 cm across all treatments while plants at Rustenburg had the lower pod clearance of 5.3 cm as shown in Figure 2d.

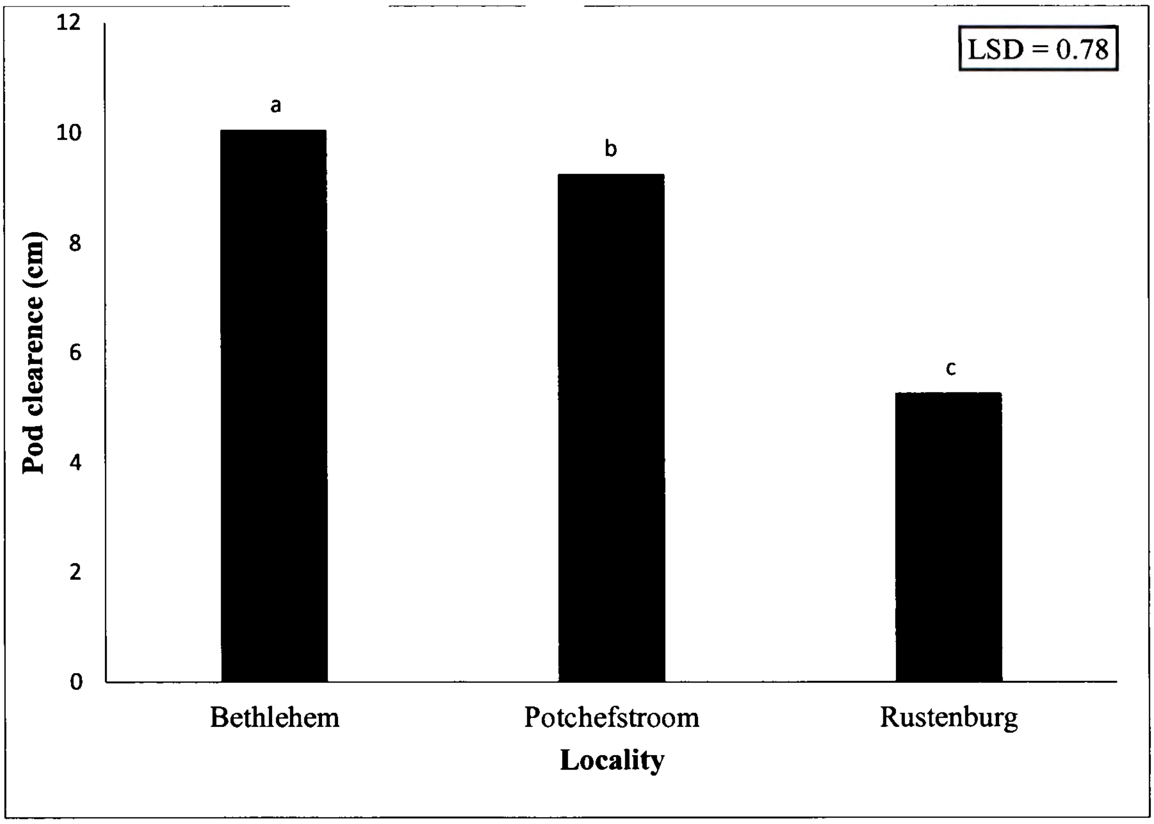

Figure 2d: Pod clearance of soybean plants across all treatments for each of the three localities

4.2.5 Variation in pod clearance for the different planting densities

The mean pod clearance of 9.4 cm obtained across the six soybean cultivars and trial localities for planting density of 450 000 plants ha^{-1} sown at 45 cm distance between rows was highest while pod clearance of 6.7 cm for a density of 200 000 plants ha^{-1} sown at 75 cm distance between rows was the least as the Figure 2e clearly shows.

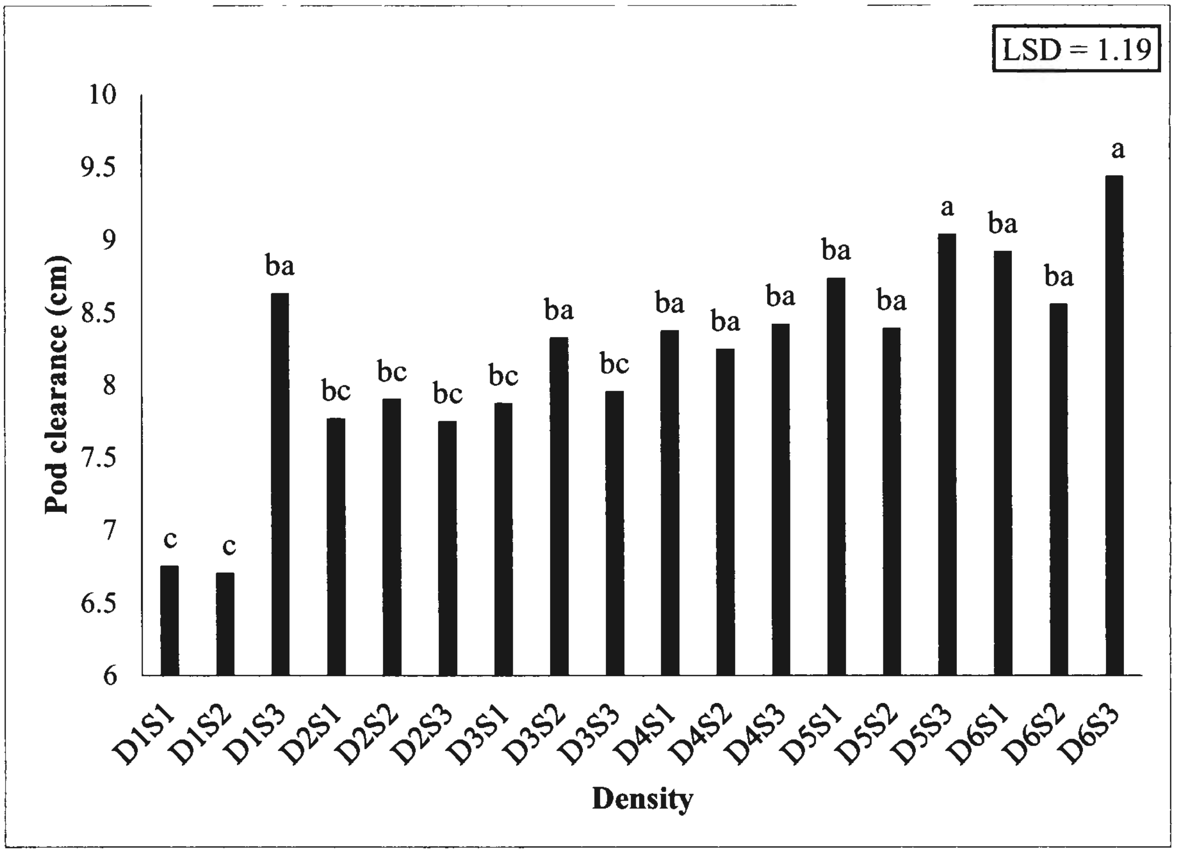

Figure 2e: Pod clearance of soybean plants for the different planting densities
D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.2.6 Variation in pod clearance for the different cultivars

Soybean cultivar PAN 1614R had the highest mean pod clearance (14.2 cm) across planting densities and localities while LS 6240R cultivar had the lowest pod clearance of 2.2 cm as shown in Figure 2f.

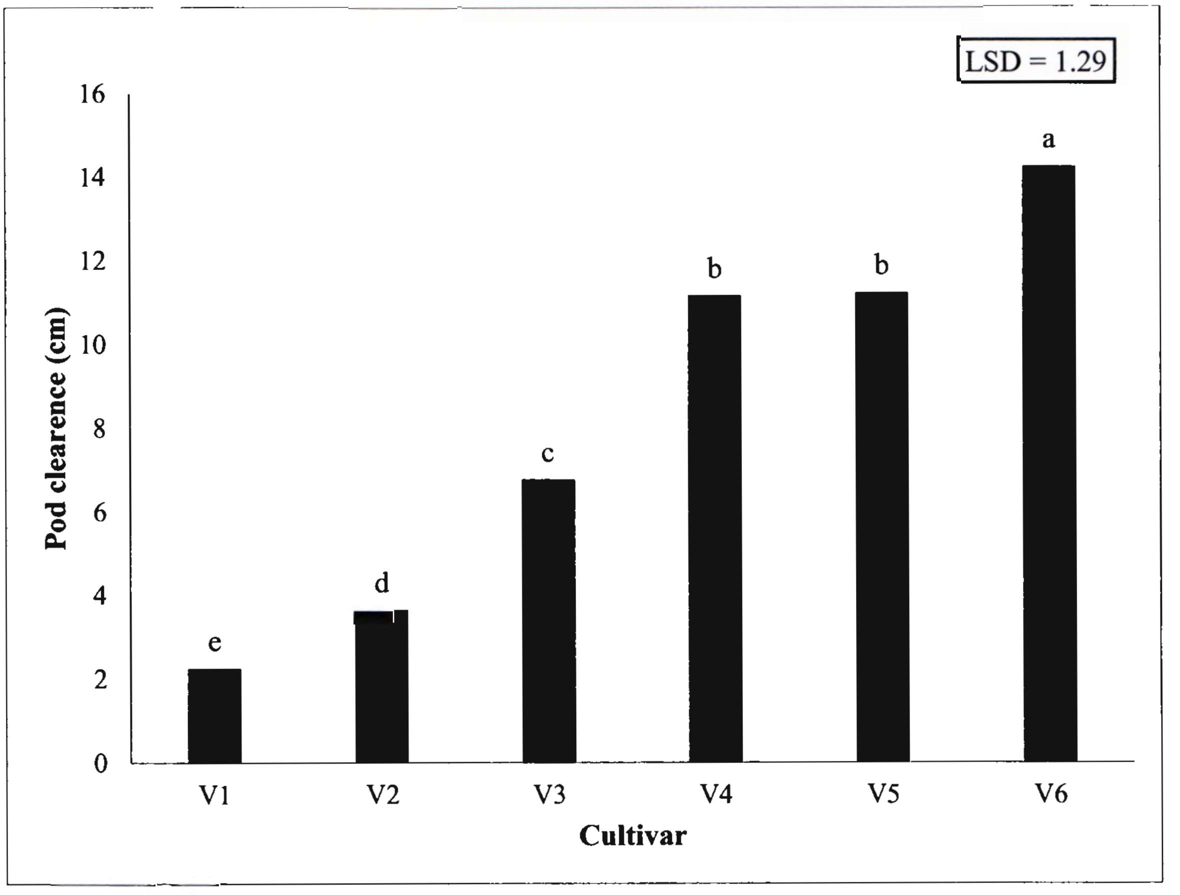

Figure 2f: Pod clearance of the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.2.7 Variation in soybean plant height for each trial locality

Soybean plant grown at Bethlehem had the highest mean plant height of 94.1 cm across all planting densities and cultivars while Rustenburg had the lowest plant height of 69.2 cm (Figure 2g).

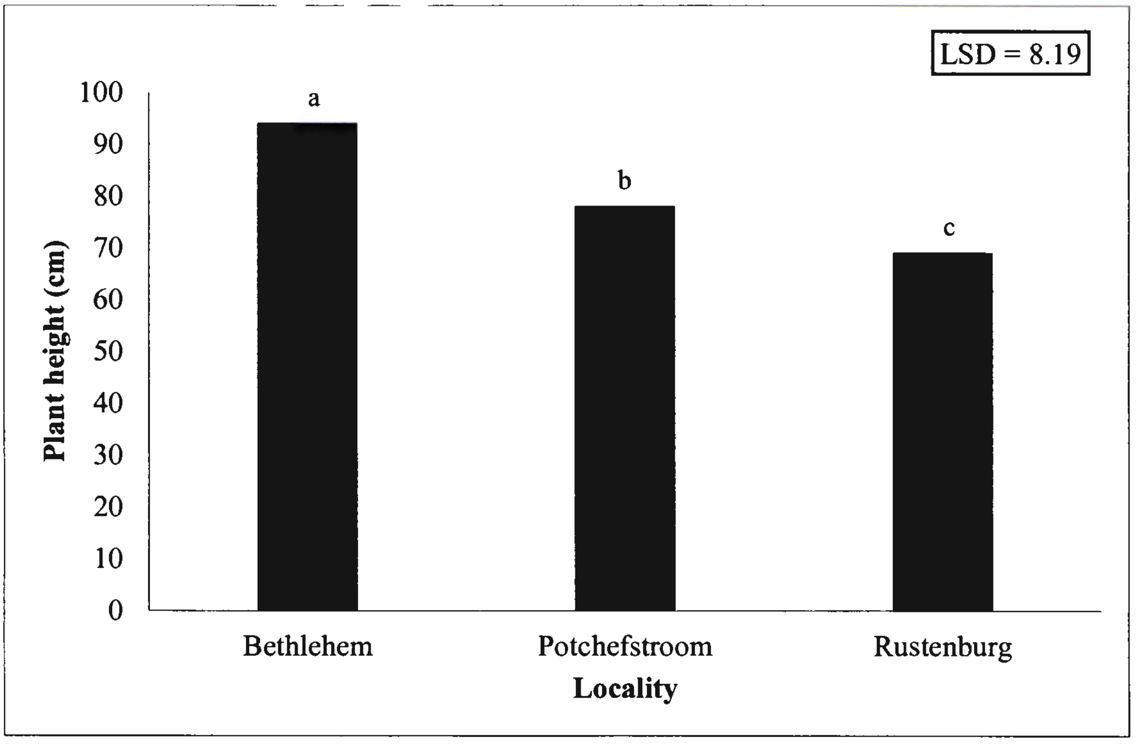

Figure 2g: Plant height at each of the three localities

4.2.8 Variation in plant height for the different planting densities

Soybean planting density of 450 000 plants ha^{-1} sown at 90 cm distance between rows had the highest mean plant height of 87.1 cm across the six soybean cultivars and planting localities among the eighteen planting densities while planting density of 200 000 plants ha^{-1} sown at 75 cm distance between rows had the least plant height of 79.4 cm (Figure 2h).

4.2.9 Variation in plant height for the different soybean cultivars

The plant height across the different plant densities and localities revealed that PAN 1614R cultivar had the tallest plant of 96.7 cm while LS 6240R cultivar had the shortest plant height of 65.5 cm (Figure 2i). Grouping of soybean cultivars based on physiological maturity duration indicates significant influence on plant growth. PAN 1614R cultivar with longer duration physiological maturity period has greater plant height than cultivar LS 6240R with relatively early physiological maturity period.

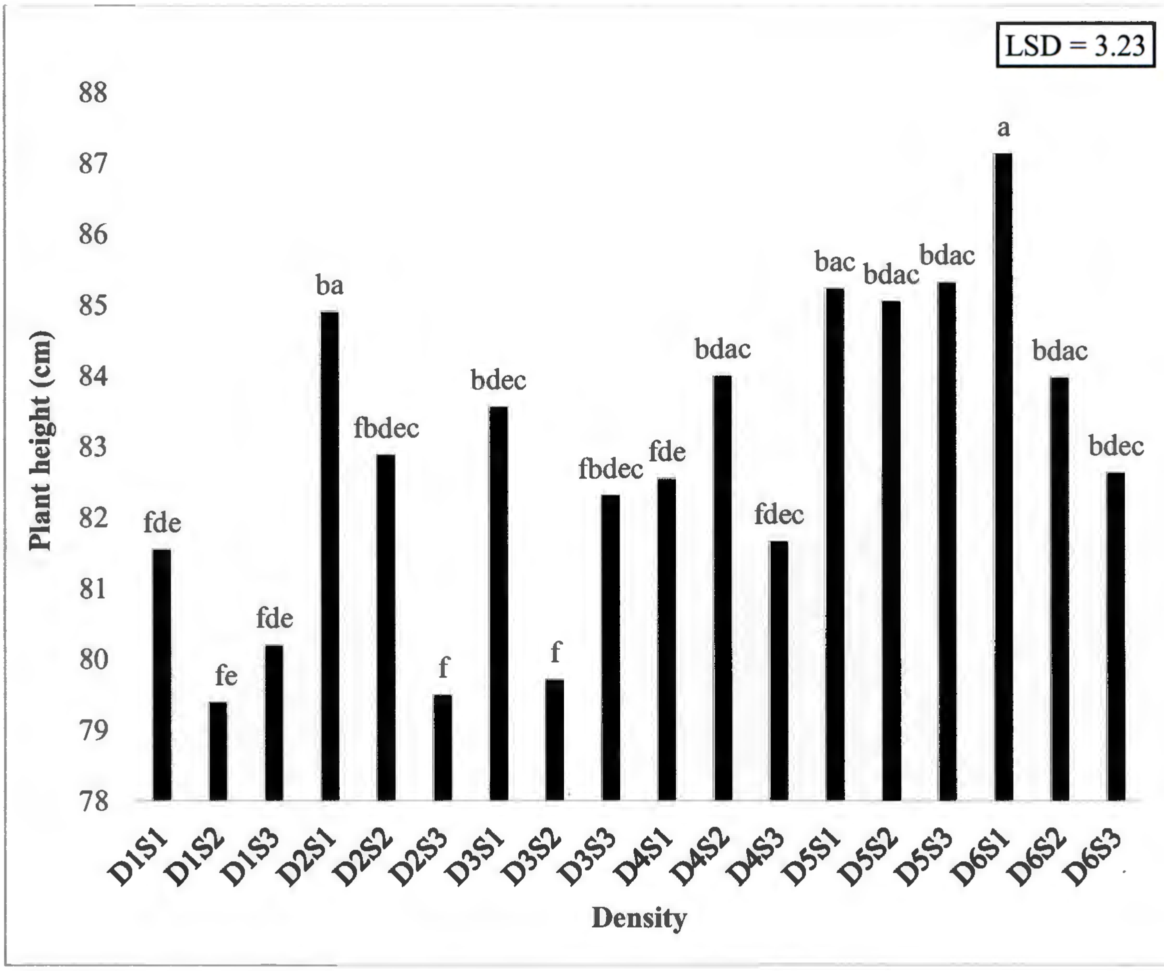

Figure 2h: Plant height of the different planting densities

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

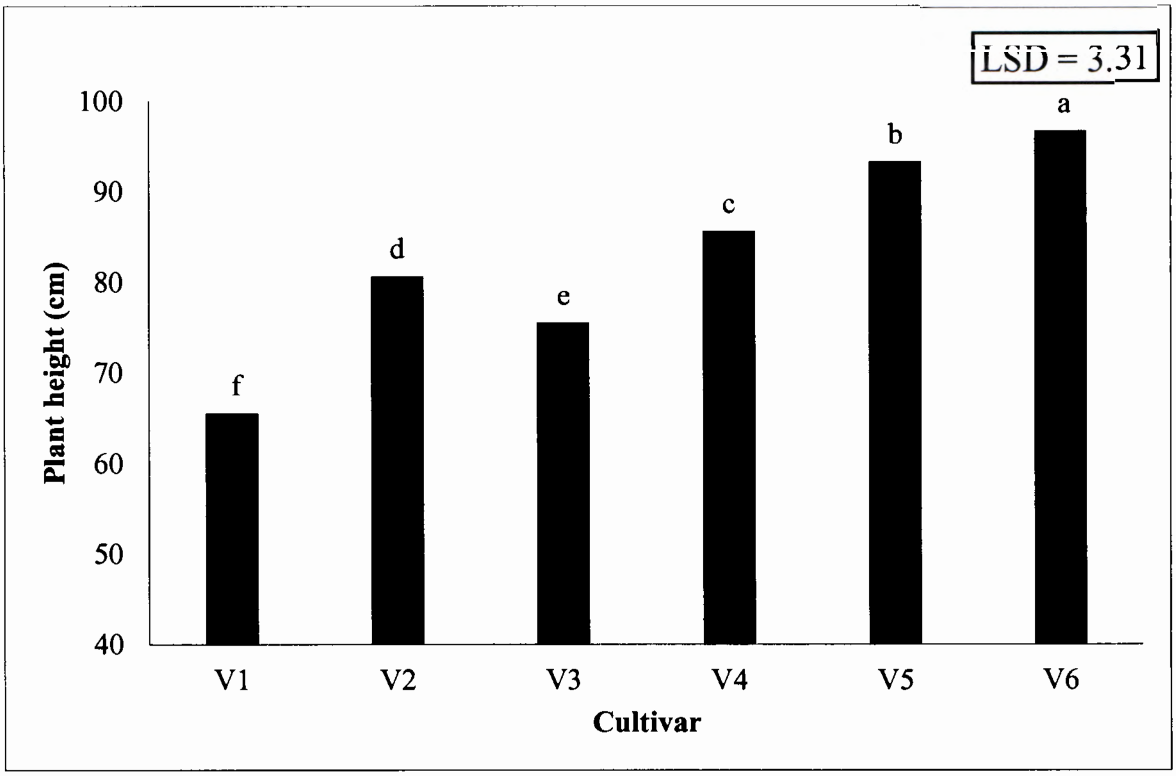

Figure 2i: Plant height of the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.3 Treatments effect on measured phenological parameters

4.3.1 Effects on duration to 50% flowering at each locality

The duration to attain 50% flowering by the different soybean cultivars was 55 day at Rustenburg but 80 days at Bethlehem (Figure 3a).

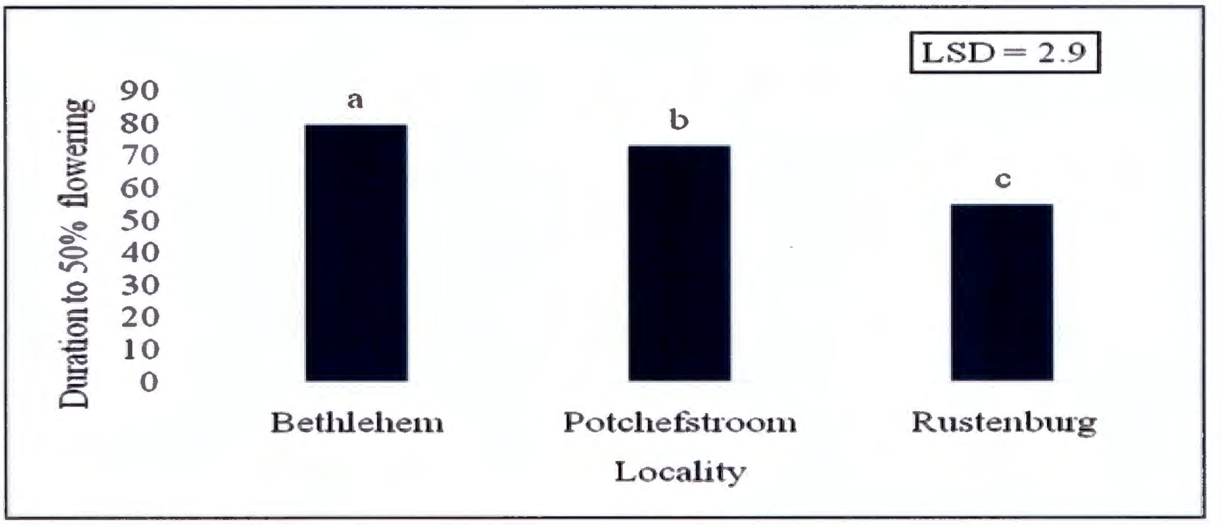

Figure 3a: Duration to 50% flowering across at the three localities

4.3.2 Effects on duration to 50% flowering for the different cultivars

Soybean cultivar LS 6240R attained 50% flowering in about 53 days while cultivar PAN 1614R took longer (about 82 days) to attain 50% flowering as shown in Figure 3b.

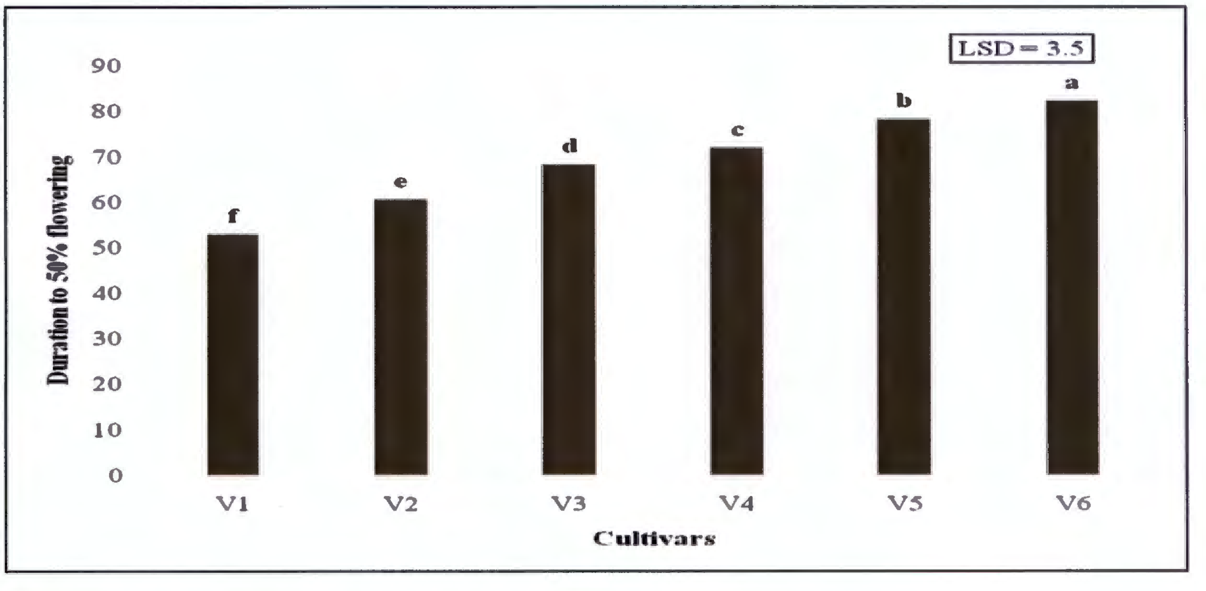

Figure 3b: Duration to 50% flowering for the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.3.3 Effects on duration to 50% physiological maturity

Soybean plants attained 50% physiological maturity much earlier at Rustenburg (130 days) while it took a much longer time (about 139 days) at Bethlehem (Figure 3c).

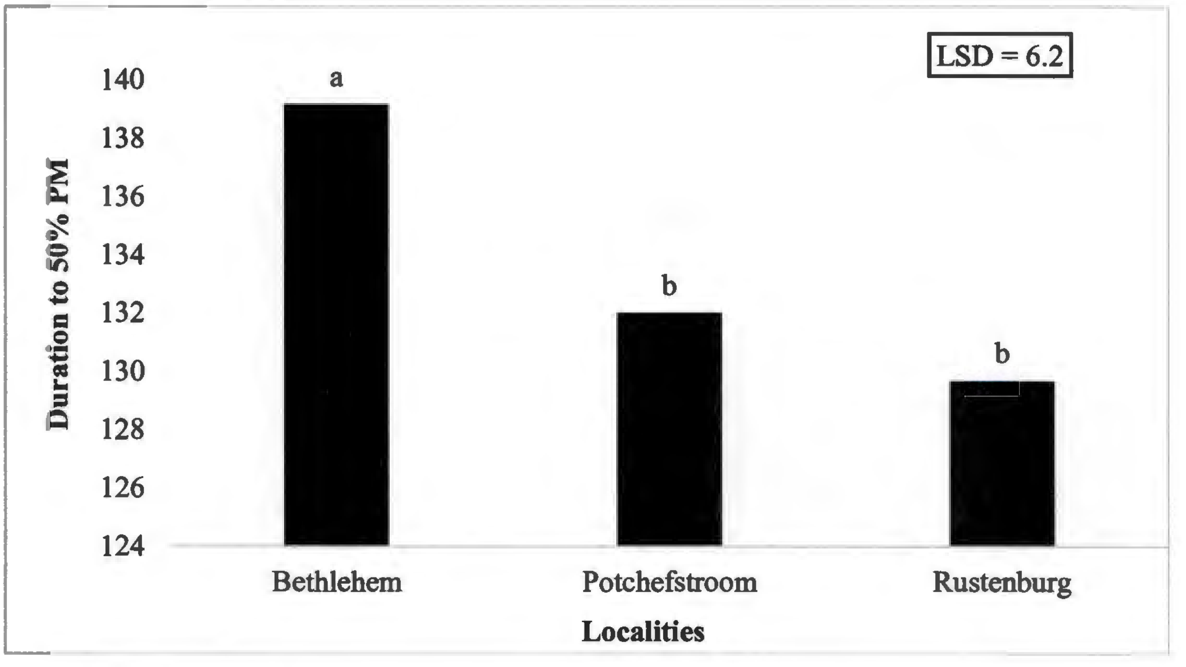

Figure 3c: Duration to 50% physiological maturity (PM) at the three localities

4.3.4 Duration to 50% physiological maturity for the different cultivars

Soybean LS 6240R cultivar had a shorter duration to 50% physiological maturity (about 125 days) across all planting densities and trial localities while cultivar PAN 1614R had the longest duration (about 141 days) as shown in figure 3d.

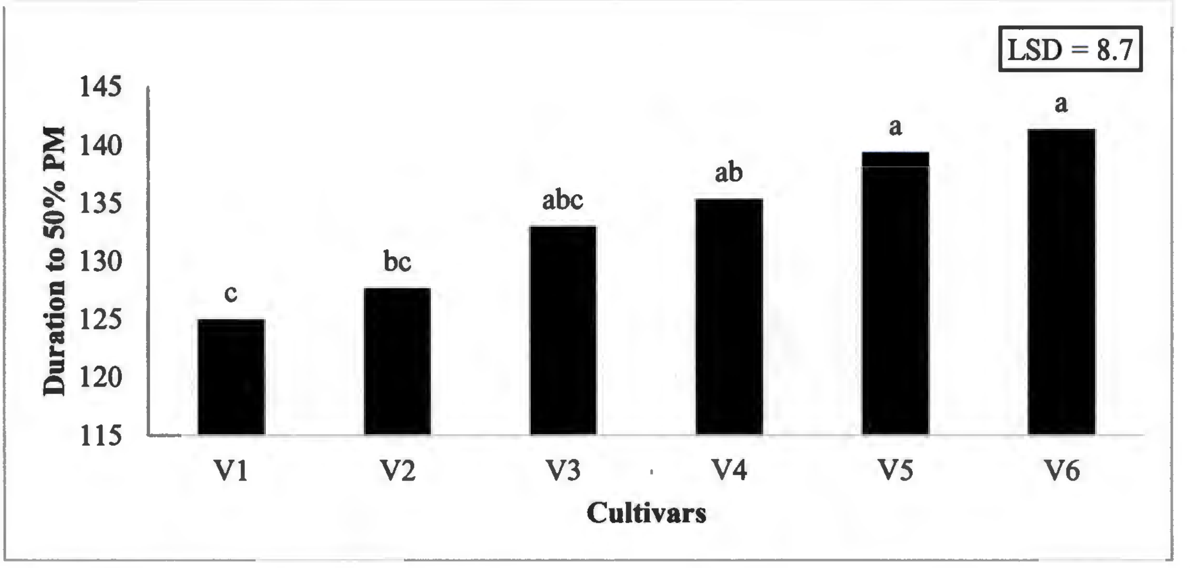

Figure 3d: Duration to 50% physiological maturity (PM) for the different soybean cultivars V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.3.5 Effects on duration to 50% harvest maturity

Across all cultivars and planting densities, soybean plants attained 50% harvest maturity much earlier at Rustenburg (about 144 days) while at Bethlehem the duration to 50% harvest maturity was about 158 days (Figure 3e).

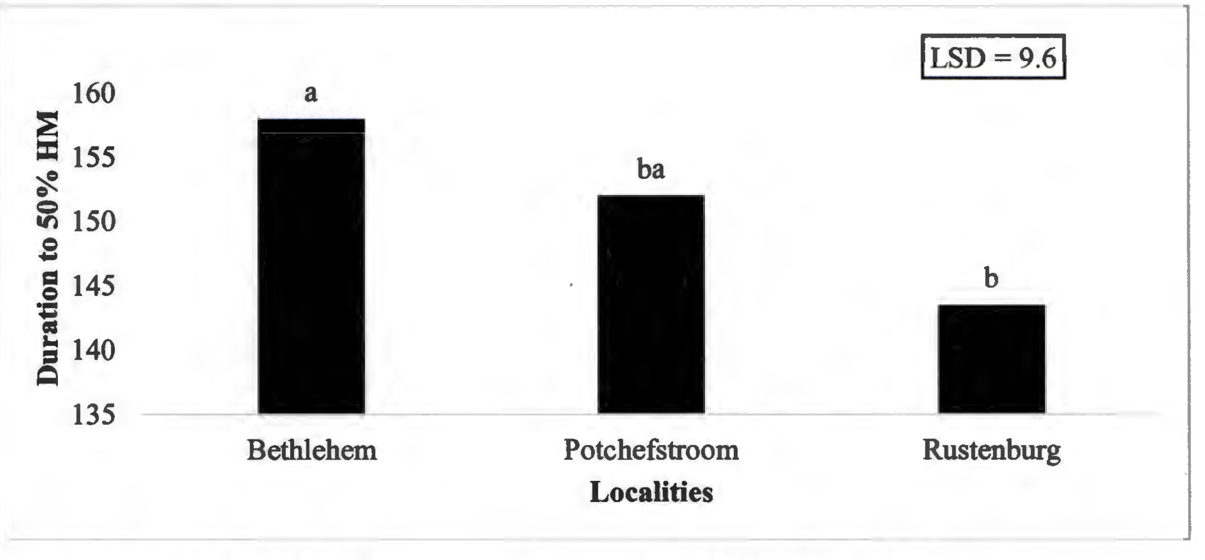

Figure 3e: Duration to 50% harvest maturity (HM) for each of the three localities

4.3.6 Effects on duration to 50% harvest maturity for the different cultivars

Soybean LS 6240R cultivar had the shortest Duration to 50% harvest maturity (about 137 days) across all localities and planting densities while cultivar PAN 1614R took longer (about 161 days) as shown in figure 3f.

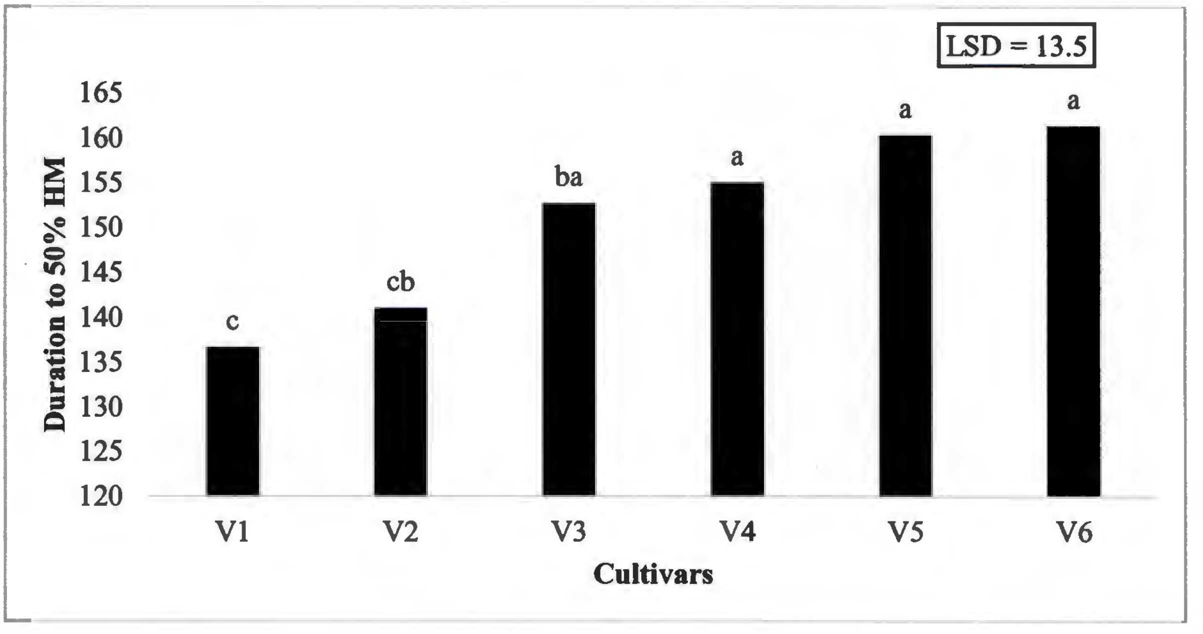

Figure 3f: Duration to 50% harvest of the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4 Treatments effect on measured yield and attributes

4.4.1 Effects on plant numbers of commercial soybean cultivar

The highest mean plant numbers of 239 461 plant ha^{-1} across all cultivars and planting densities was obtained at Rustenburg while the lower number of 141 334 plants ha^{-1} was obtained at Potchefstroom as shown in the Figure 4a below.

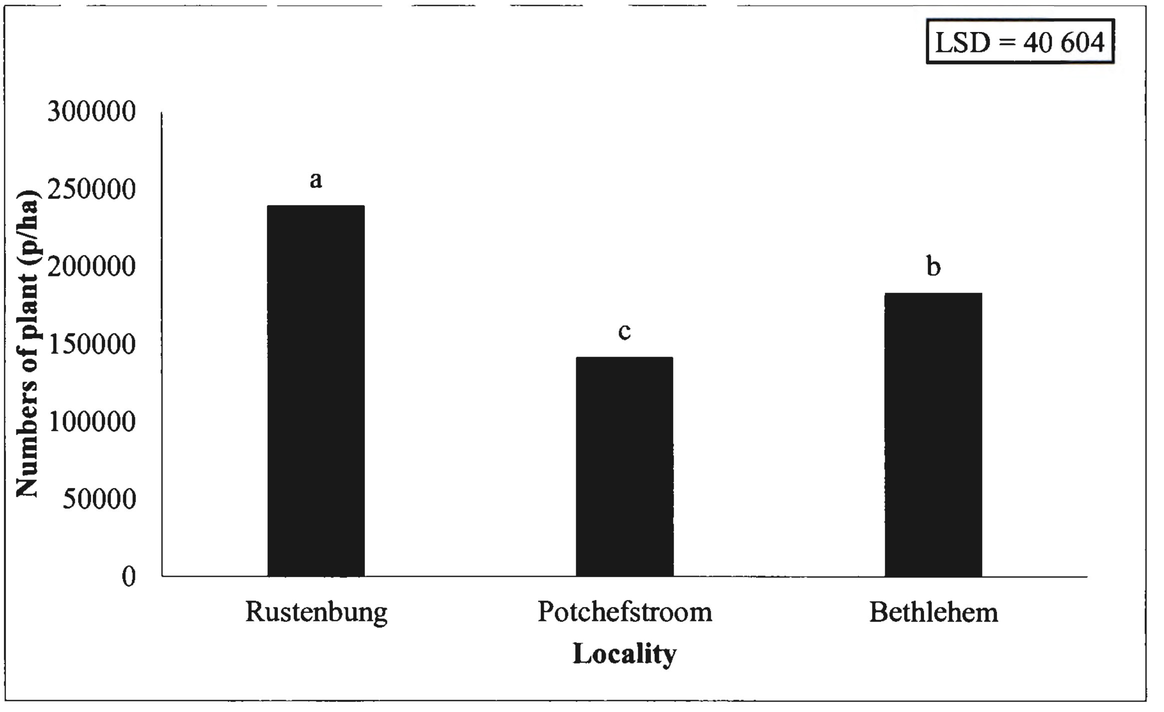

Figure 4a: Number of plants for each of the three localities

4.4.2 Effects of planting density on mean plant numbers

Plant density of 450 000 plants ha^{-1} and 45 cm inter-row spacing (D6S3) gave the highest mean number of plants (280 633 ha^{-1}) across soybean cultivars and trial localities while plant density of 200 000 plants ha^{-1} and 75 cm spacing between rows had the lowest number of 111 898 plants ha^{-1} as shown in the figure 4b. Proper plant density during soybean growth period is very important to reduce competition between plants and making nutrients more available to plants. Soybean is very sensitive, and can die when the nutrients are inadequate while low plant density could result in space wastage and the growth of weeds on field.

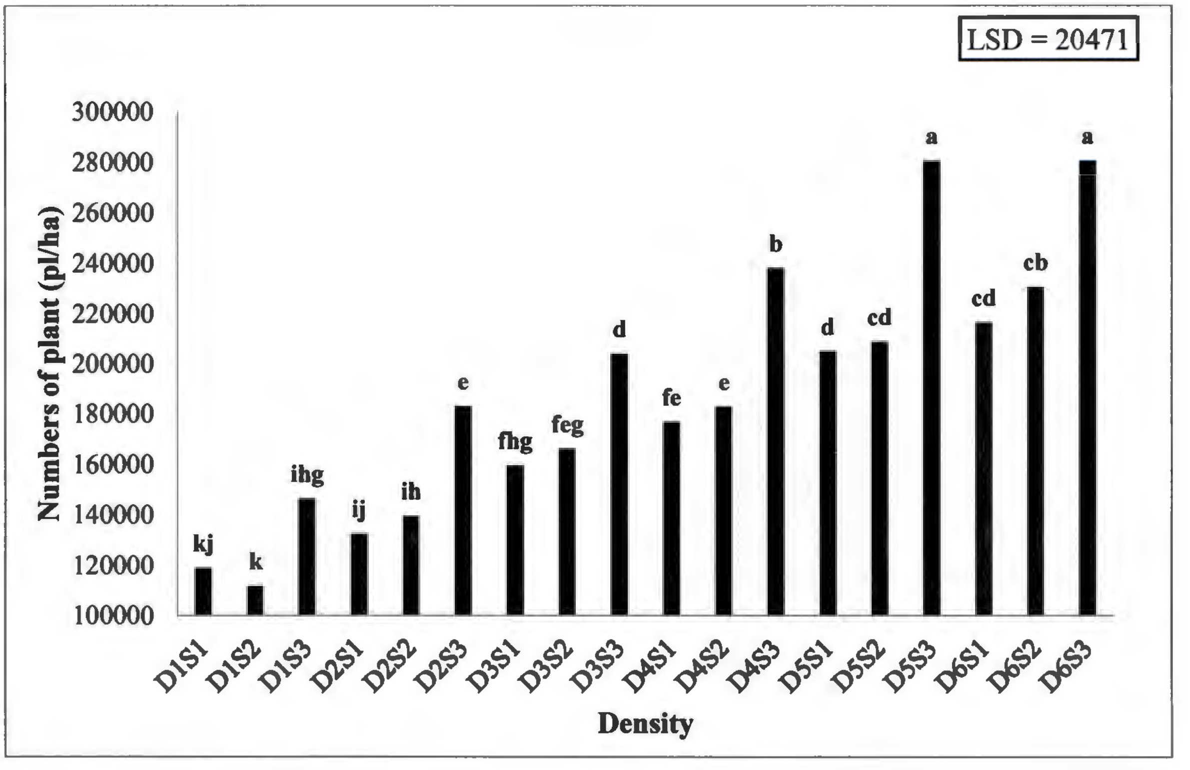

Figure 4b: Numbers of plant at different planting densities

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.4.3 Effects of cultivar on number of plants

Soybean cultivar PAN 1614R had the highest mean number of 212 976 plants ha^{-1} across all localities and planting densities while LS 6240R cultivar had the lowest number of 153 699 plants ha^{-1} as shown in Figure 4c. The importance of plant count at harvest is aimed at assisting in predicting the final grain yield based on actual plant population observed as opposed to the calculated plant population at the initiation of the study.

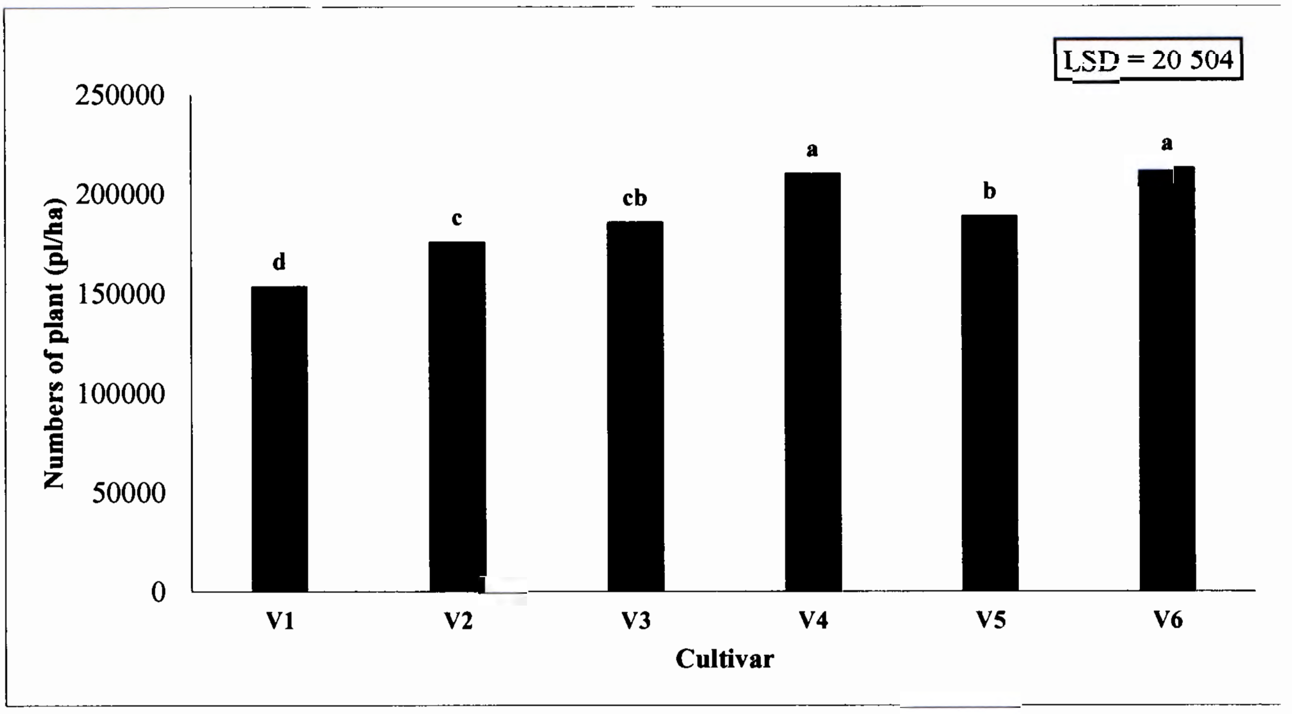

Figure 4c: Number of plant for the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.4 Weight of 100-seeds of commercial soybean cultivar at different locations

The highest mean of 100-seed weight of 20.1g across all cultivars and planting densities was obtained from Rustenburg trial while the least weight of 16.5 g was obtained at Potchefstroom trial as shown in the Figure 4d.

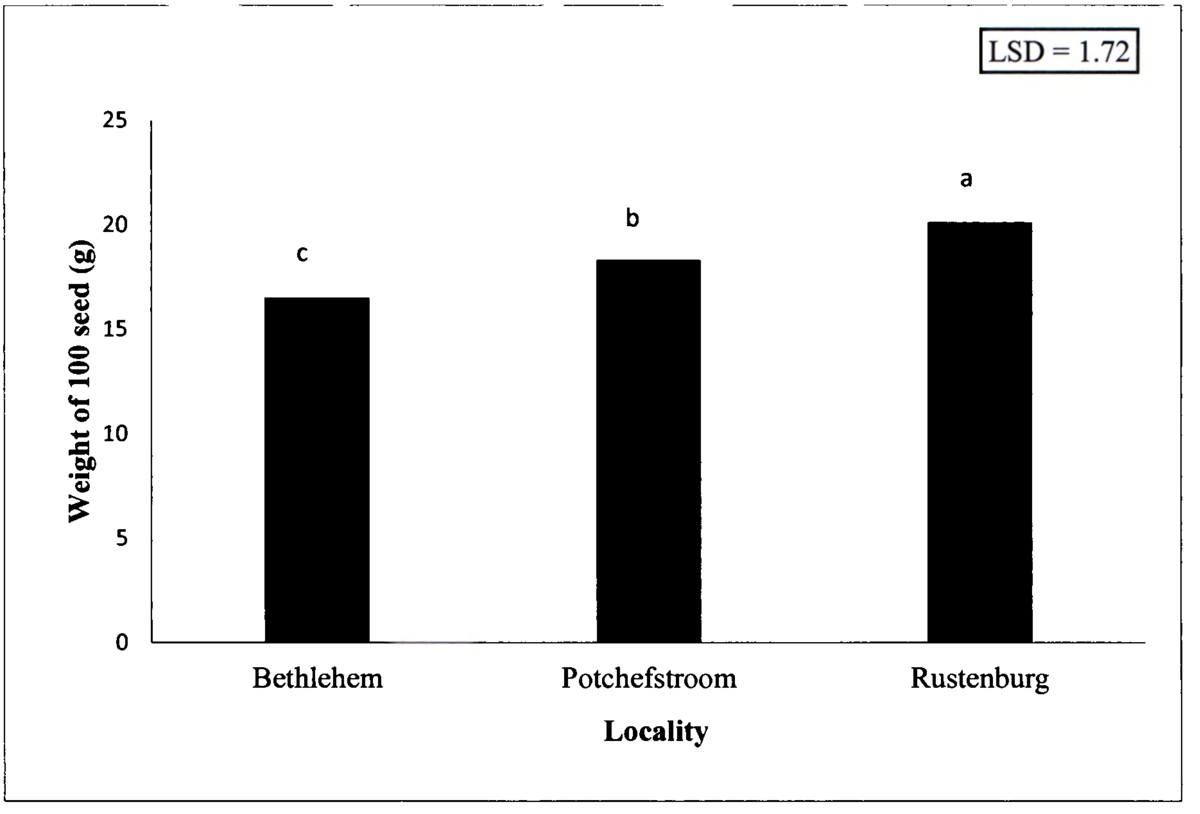

Figure 4d: Weight of 100-seeds for each of the three localities

4.4.5 Effects of cultivar on weight of 100-seeds

Soybean LS 6240R cultivar had the highest 100-seed weight of 21.1g across all localities and planting densities while LS 6164R cultivar had the lowest 100-seed weight of 16.6g as shown in Figure 4e.

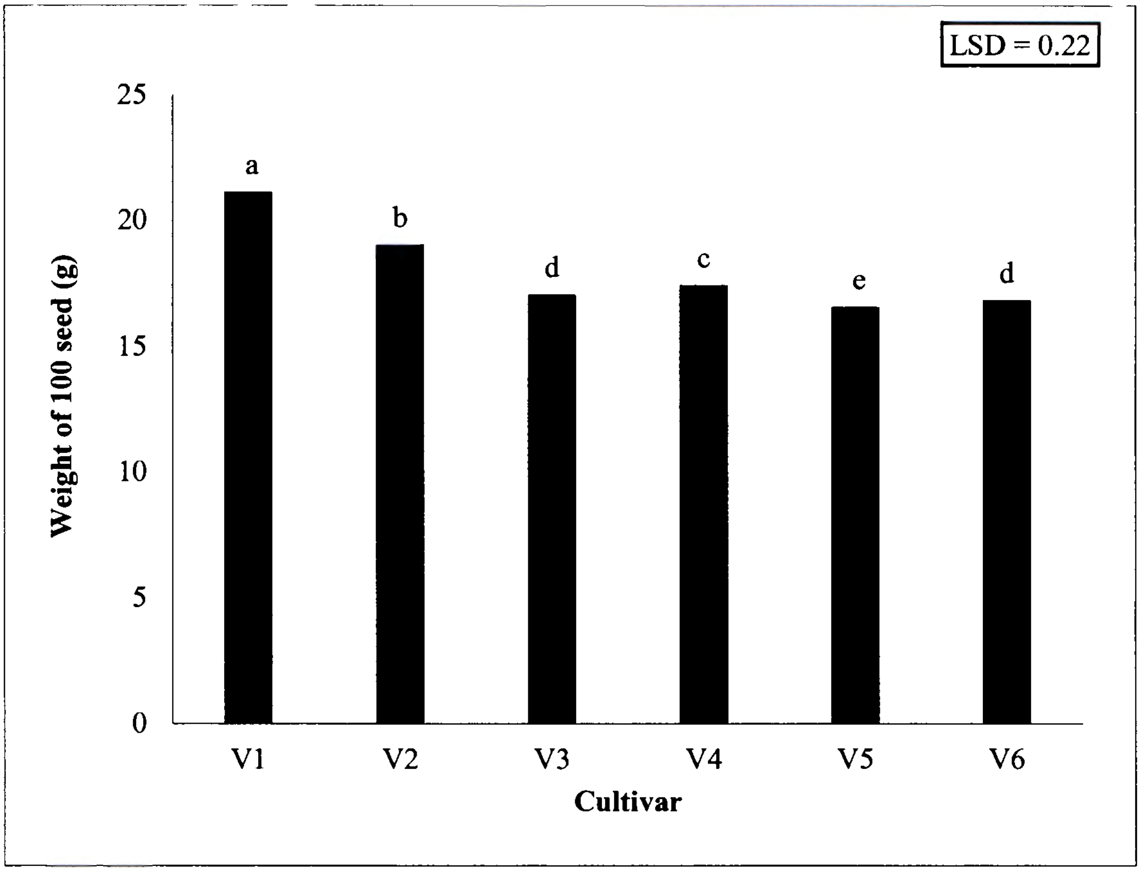

Figure 4e: Weight of 100-seeds for the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.6 Percentage seed moisture content of soybean cultivars across the three localities

The seed moisture content of 12.3% across all planting densities for the different soybean cultivars planted at Rustenburg was highest while the lowest value of 10.4% was obtained at Potchefstroom as shown in the Figure 4f.

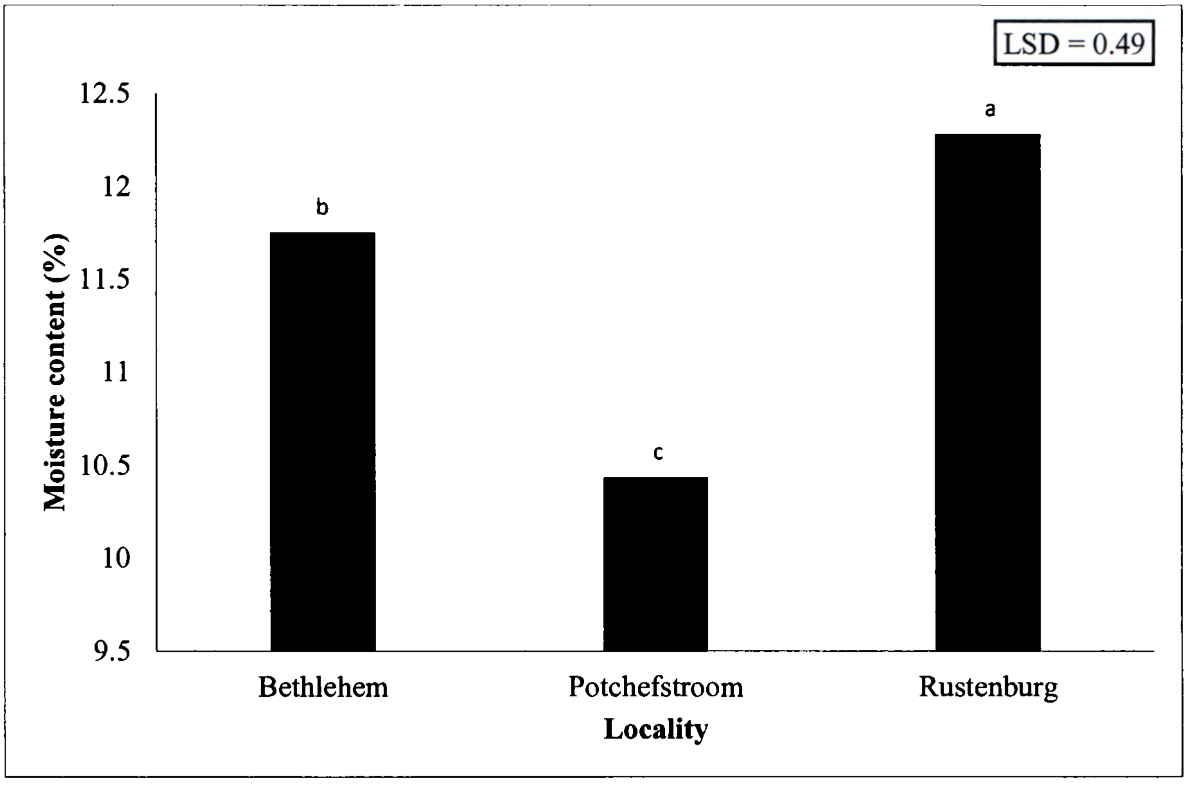

Figure 4f: Percentage seed moisture content at the three localities

4.4.7 Effects of variation in soybean cultivars on seed moisture content

Soybean cultivar LS 6240R had the highest mean moisture content of 11.3% across all localities and planting densities while PAN 1454R cultivar had the lowest moisture of 10.95% as shown in Figure 4g.

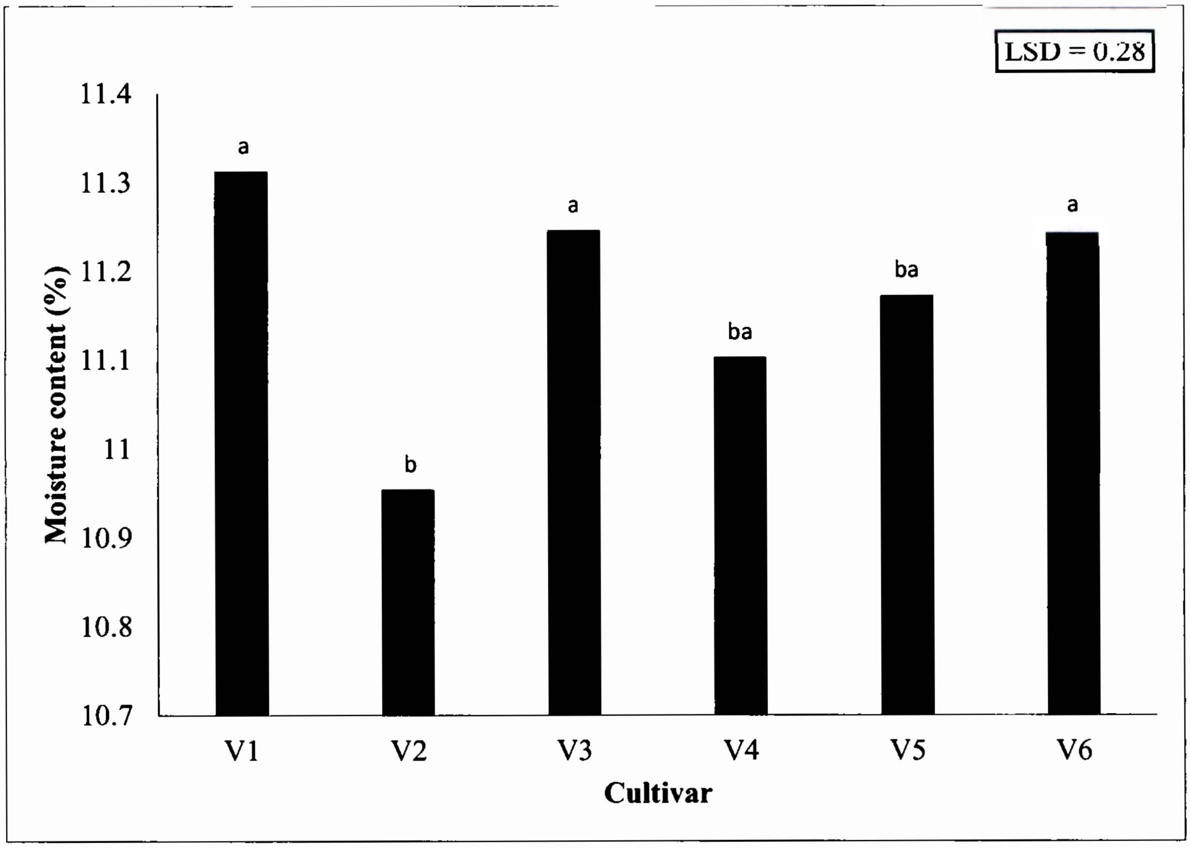

Figure 4g: Percentage seed moisture content for the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.8 Grain yield obtained at the different localities

The highest grain yield of 4 389.5 kg ha^{-1} across all cultivars and planting densities was obtained from Potchefstroom trial while the lowest yield of 3 409.5 kg ha^{-1} was obtained at Rustenburg as shown in the Figure 4h.

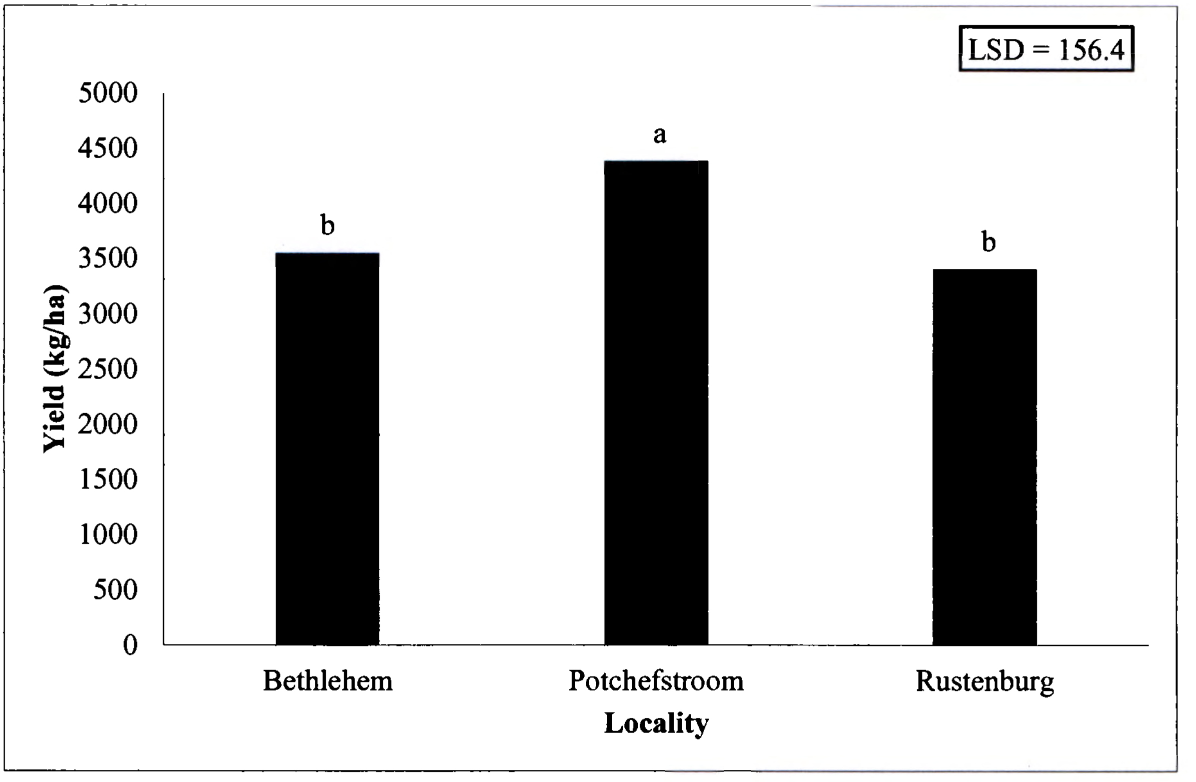

Figure 4h: Grain yield obtained from the three localities

4.4.9 Grain yield at the different planting densities

Soybean plant density of 400 000 plants ha^{-1} and a spacing of 45 cm between rows (D5S3) gave the highest grain yield of 5 176.0 kg ha^{-1} while density of 200 000 plants ha^{-1} with seeds sown at 90 cm spacing between rows (D1S1) gave the lowest grain yield of 3 085.1 kg ha^{-1} as shown in the Figure 4i.

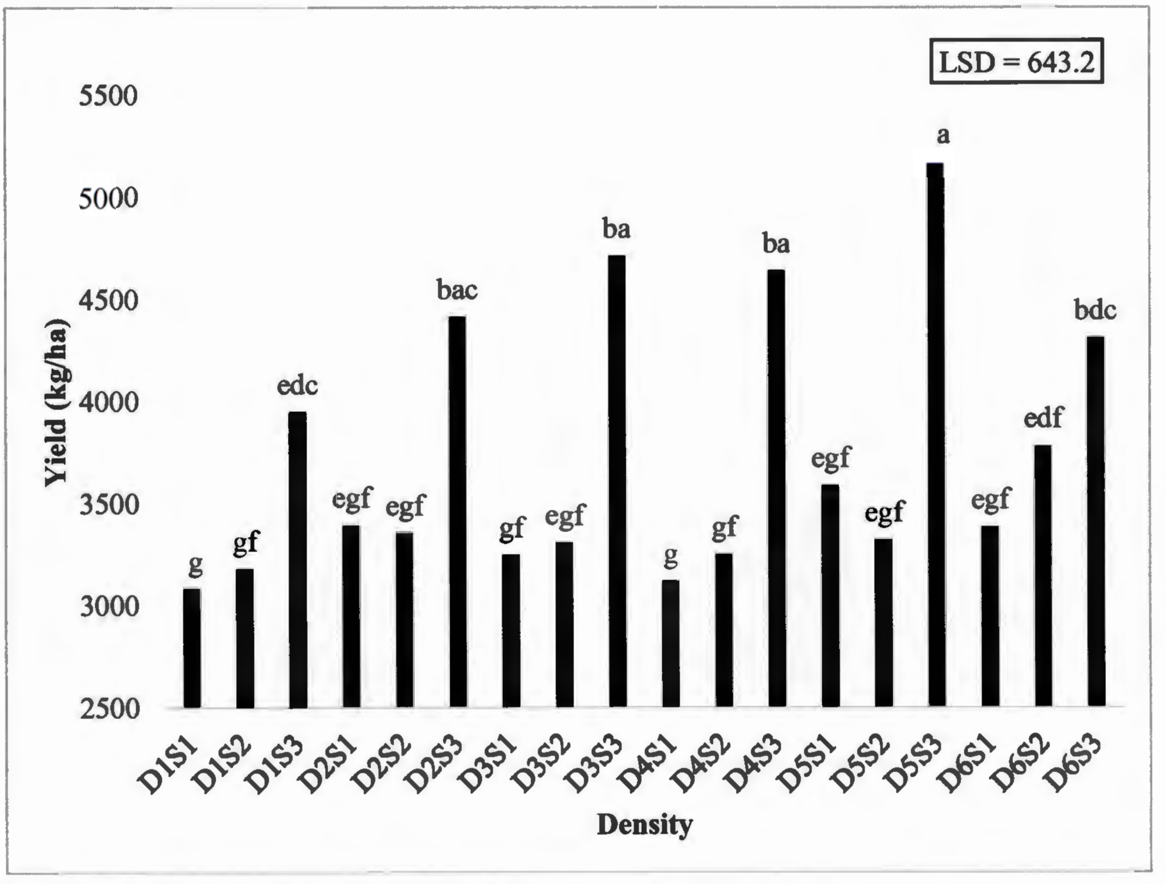

Figure 4i: Grain yield of the different planting densities

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.4.10 Seed protein content of soybean cultivars at different localities

The highest mean seed protein content of 44.1% across all soybean cultivars and planting densities was obtained at Rustenburg while the lowest seed protein content of 41.1% was obtained at Potchefstroom as shown in the Figure 4j.

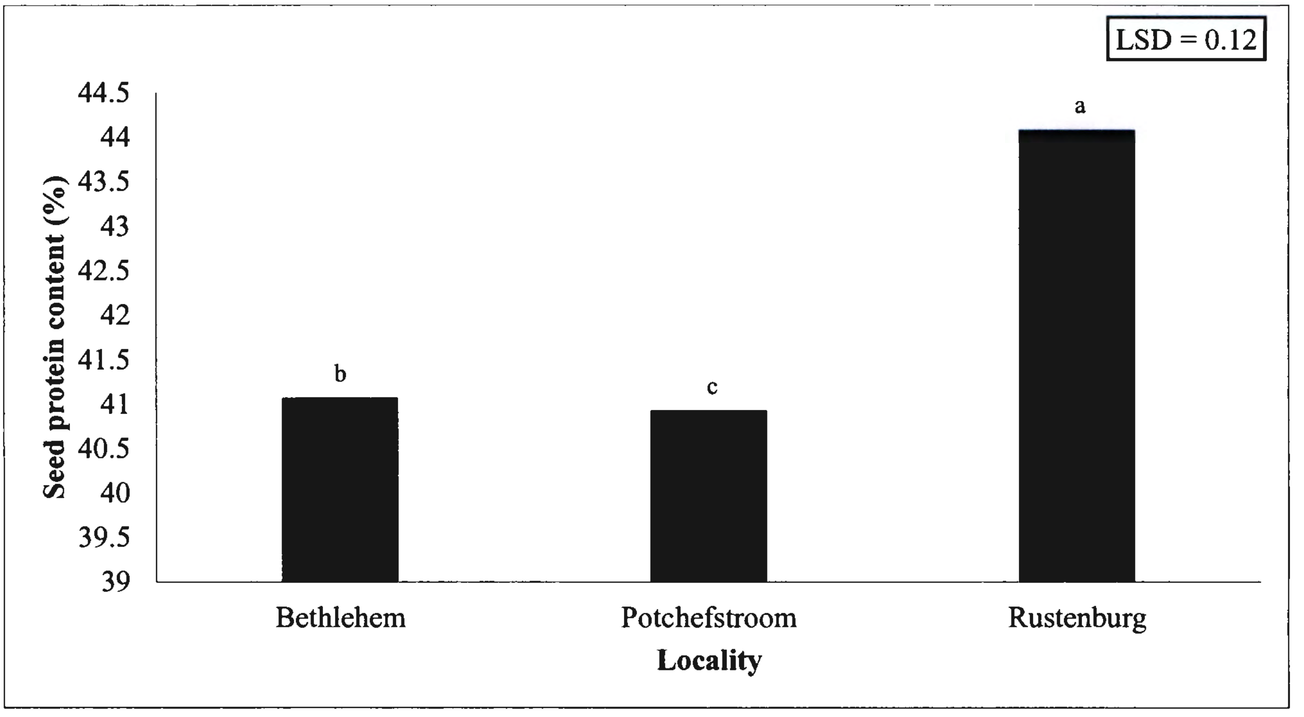

Figure 4j: Percentage of seed protein content for each of the three localities

4.4.11 Effects on seed protein content for the different planting densities

The seed protein content obtained from current study ranged from 40.4% to 44.5% across all localities, cultivars and planting densities. Planting density exerted a significant effect on the percentage protein content. Plant density of 400 000 plants ha^{-1} obtained at 90 cm between rows (D5S1) gave the highest seed protein of 42.3% while 250 000 plants ha^{-1} at 90 cm between rows (D2S1) gave the lowest seed protein of 41.8 %, as shown in Figure 4k.

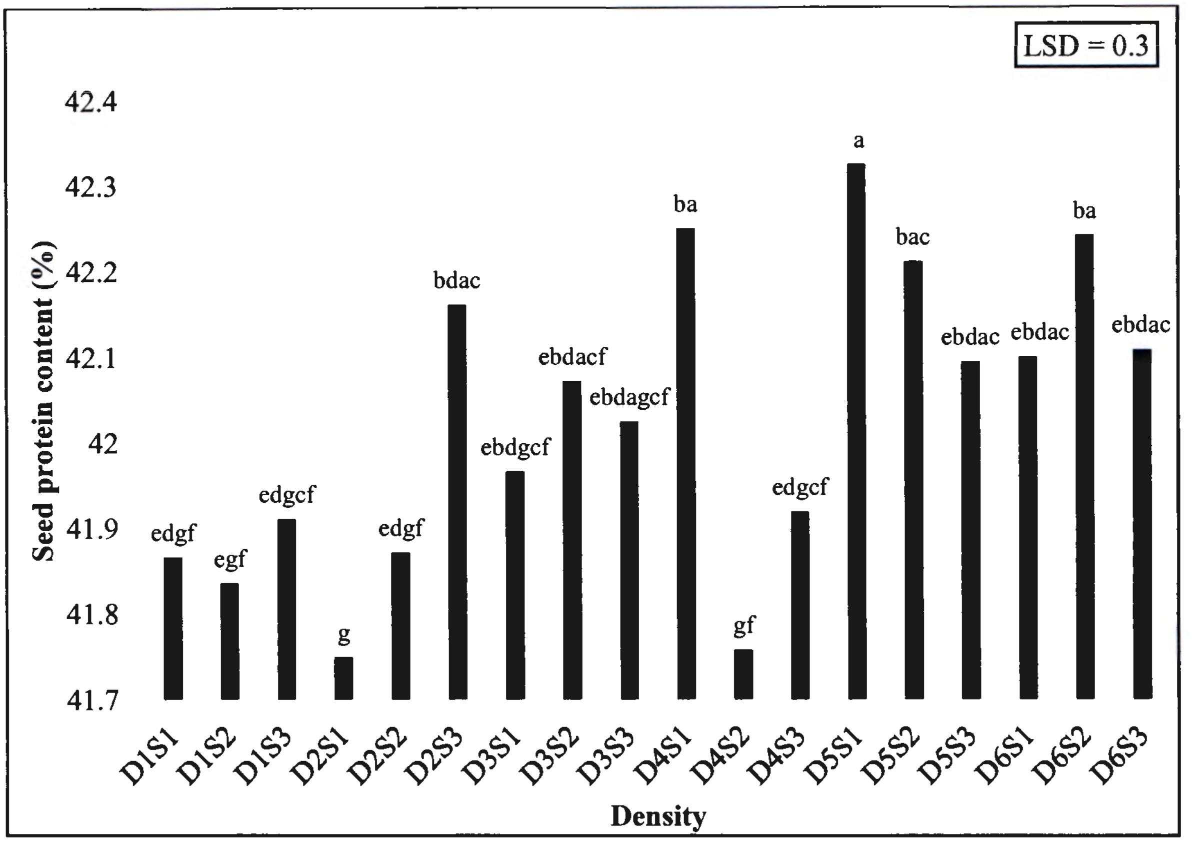

Figure 4k: Percentage seed protein content for the different planting densities

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.4.12 Effects on protein content of different soybean cultivars

Soybean cultivar PAN 1500R had the highest mean seed protein content of 43.5% across all localities and planting densities while cultivar PAN 1664R had the lowest seed protein content of 40.7% as shown in the Figure 4l.

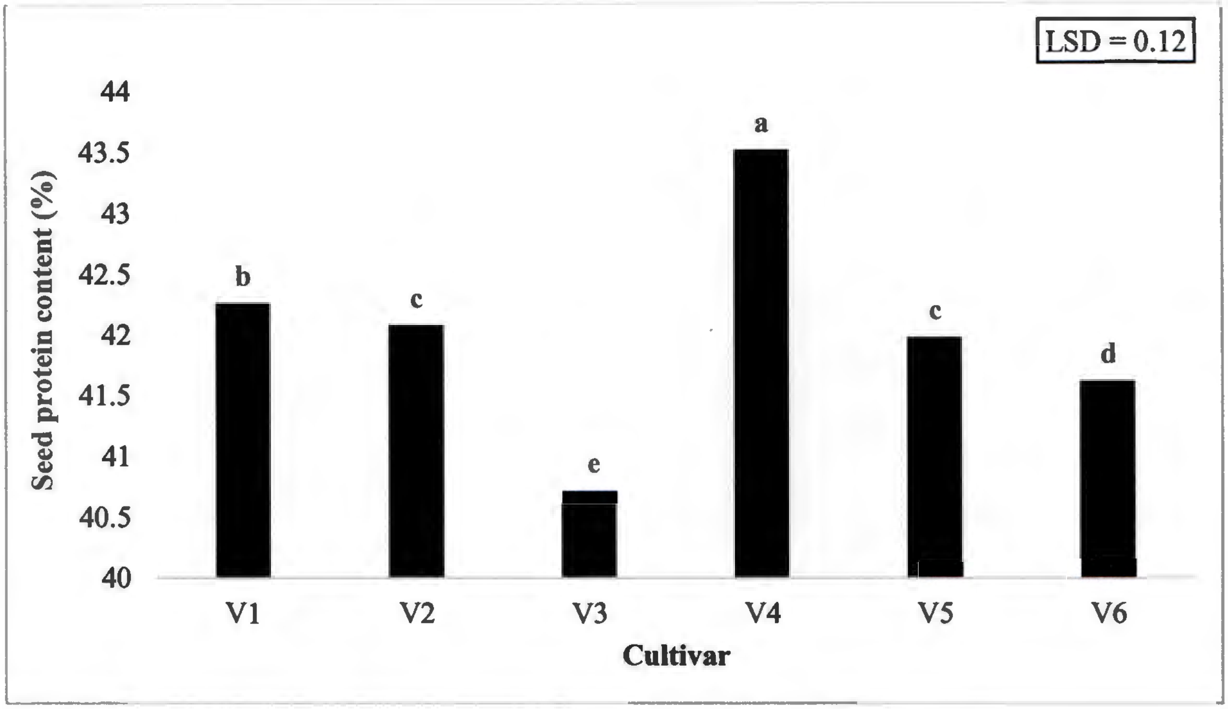

Figure 4l: Percentage of seed protein content of the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.13 Oil content of soybean cultivars measured at different localities

Soybean seeds that produced the highest mean percentage oil content (21.0%) across all cultivars and planting densities was harvested at Potchefstroom while soybean seeds from Bethlehem trial had the lowest percentage oil content of 20.0% (Figure 4m).

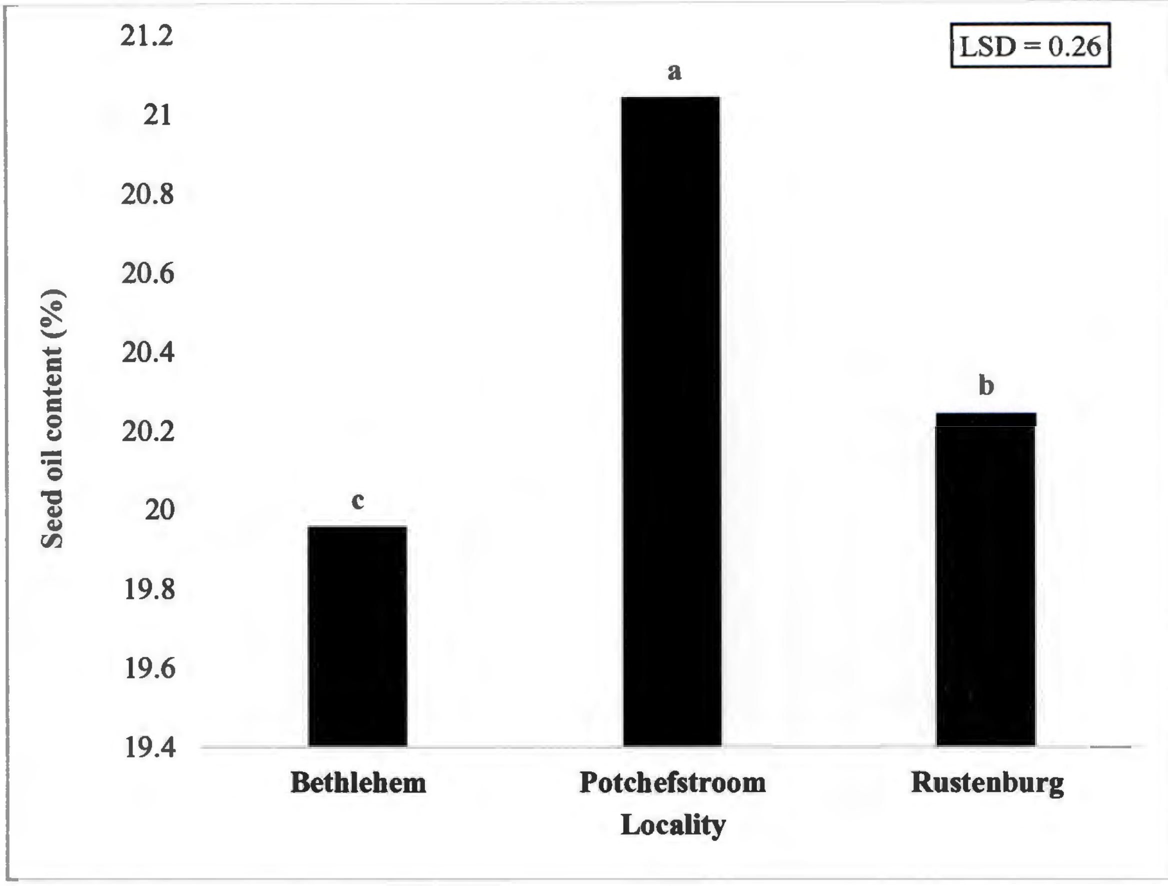

Figure 4m: Percentage of seed oil content for each of the three localities

4.4.14 Effects of planting density on seed oil content

Plant density of 350 000 plants ha^{-1} with seed sown at 75 cm between rows (D4S2) had the highest percentage seed oil content of 20.6% while density of 450 000 plants ha^{-1} at 45 cm row spacing (D6S3) had lowest percentage seed oil content of 20.3%, as shown in Figure 4n.

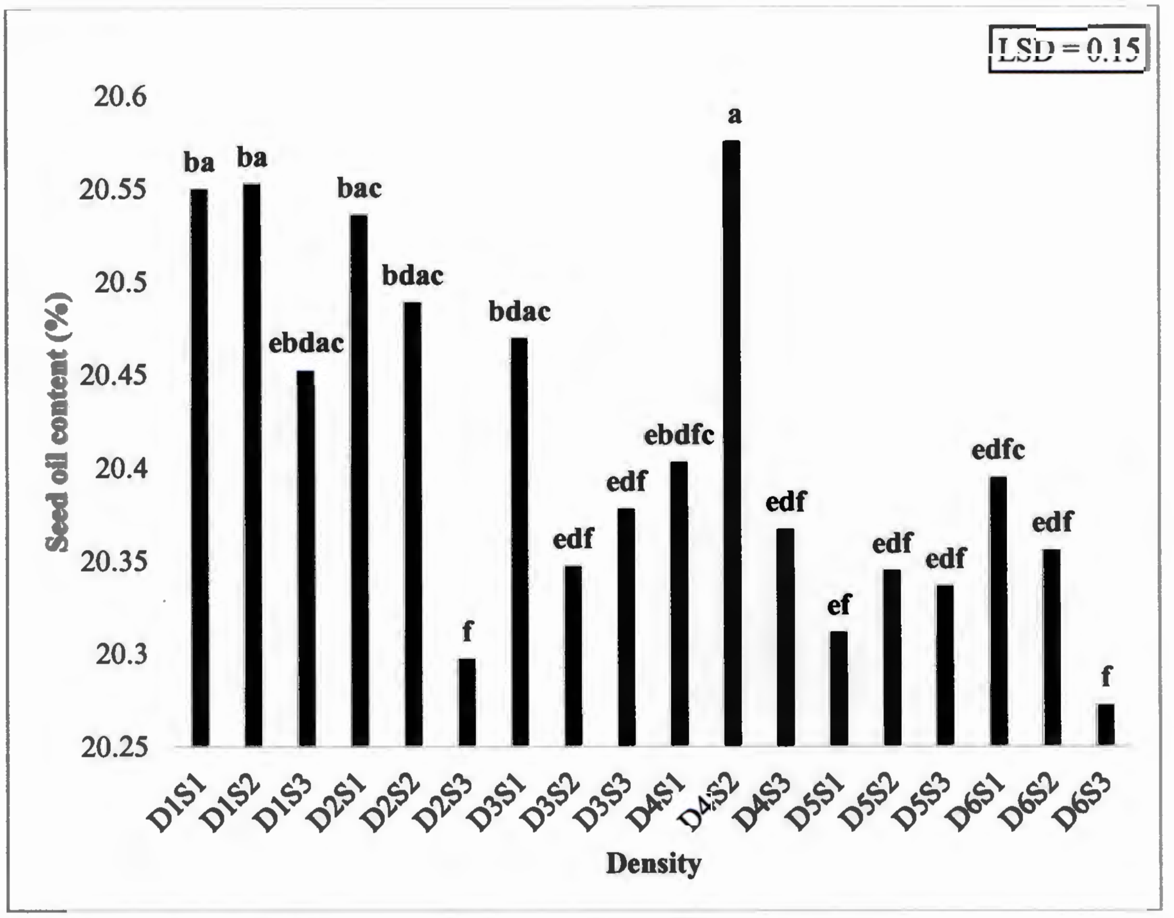

Figure 4n: Percentage seed oil content for the different planting densities
D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.4.15 Effects of soybean cultivars on seed oil content

Soybean seeds from cultivar LS 6240R had the highest mean percentage oil content of 21.1% across all localities and planting densities while seeds from cultivar PAN 1500R had the lowest percentage oil content of 19.7% as shown in the Figure 4o.

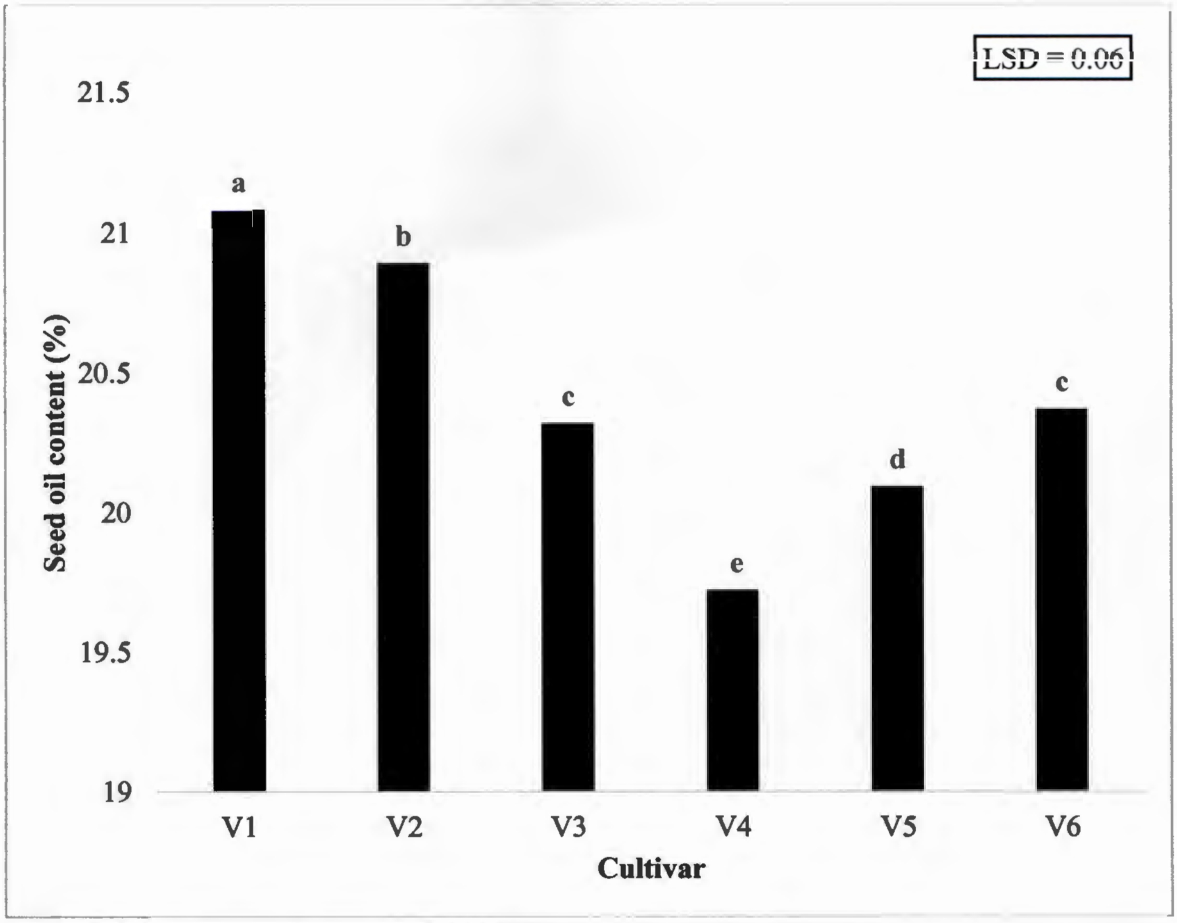

Figure 4o: Percentage of seed oil content for the different soybean cultivars

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5 Treatments interaction effects on all measured variables

4.5.1 Locality and density interaction effect on percentage seedling emergence

Soybean planting density of 300 000 plants ha^{-1} sown at 45 cm inter-row spacing at Potchefstroom gave the highest mean seedling emergence 85.5% while density of 450 000 plants ha^{-1} sown at 90 cm inter-row spacing at Bethlehem gave the lowest percentage emergence of 49.2% (Table 4.2).

Table 4.2: Locality x plant density interaction effect on percentage seedling emergence (E), plant population (NP), grain yield (Y) and seed protein content (P).

Bethlehem	D1S1	60.4	cba	129167	edcba	3131.3	dcba	40.7	cba
Bethlehem	D1S2	62.0	cba	125694	edcba	3243.6	dcba	40.7	cba
Bethlehem	D1S3	59.9	cba	141435	edcba	3728.2	dcba	41.0	cba
Bethlehem	D2S1	56.1	cba	126620	edcba	3273.7	dcba	40.7	cba
Bethlehem	D2S2	57.1	cba	140000	edcba	3128.6	dcba	40.8	cba
Bethlehem	D2S3	58.8	cba	156713	edcba	3825.4	dcba	41.5	cba
Bethlehem	D3S1	51.5	cb	163079	edcba	3289.2	dcba	41.2	cba
Bethlehem	D3S2	63.6	cba	170972	edcba	3235.7	dcba	41.4	cba
Bethlehem	D3S3	59.8	cba	185185	edcba	4386.0	dcba	41.3	cba
Bethlehem	D4S1	55.0	cba	184722	edcba	3350.4	dcba	41.4	cba
Bethlehem	D4S2	59.2	cba	175972	edcba	3258.7	dcba	40.7	cba
Bethlehem	D4S3	61.4	cba	218750	edcba	3828.9	dcba	40.9	cba
Bethlehem	D5S1	51.7	cb	193750	edcba	3422.2	dcba	41.1	cba
Bethlehem	D5S2	55.1	cba	230695	edcba	3227.1	dcba	41.2	cba
Bethlehem	D5S3	61.1	cba	261806	edcba	5251.2	dcba	41.3	cba
Bethlehem	D6S1	49.2	c	201505	edcba	3306.7	dcba	40.7	cba
Bethlehem	D6S2	52.0	cba	253333	edcba	3335.0	dcba	41.3	cba
Bethlehem	D6S3	59.3	cba	233333	edcba	3734.5	dcba	41.3	cba
Potchefstroom	D1S1	78.5	cba	76389	ed	3280.2	dcba	40.9	cba
Potchefstroom	D1S2	61.3	cba	64028	e	3332.8	dcba	40.7	cba
Potchefstroom	D1S3	75.9	cba	113194	edcba	5024.5	dcba	40.4	c
Potchefstroom	D2S1	75.4	cba	93287	edc	3827.3	dcba	40.7	cba
Potchefstroom	D2S2	58.7	cba	101806	edcb	3937.5	dcba	40.7	cba
Potchefstroom	D2S3	72.8	cba	151157	edcba	5932.2	ba	40.5	c
Potchefstroom	D3S1	76.9	cba	108333	edcba	3572.1	dcba	40.9	cba
Potchefstroom	D3S2	70.6	cba	119722	edcba	3867.4	dcba	41.1	cba
Potchefstroom	D3S3	85.5	a	176389	edcba	5911.7	cba	40.8	cba
Potchefstroom	D4S1	69.1	cba	121412	edcba	3639.0	dcba	41.3	cba
Potchefstroom	D4S2	77.7	cba	127917	edcba	3687.5	dcba	41.1	cba
Potchefstroom	D4S3	80.0	cba	198843	edcba	5762.4	dcba	40.7	cba
Potchefstroom	D5S1	75.6	cba	154398	edcba	3725.4	dcba	41.5	cba
Potchefstroom	D5S2	79.2	cba	135695	edcba	3924.5	dcba	40.9	cba
Potchefstroom	D5S3	82.2	cba	237037	edcba	6004.1	a	41.0	cba
Potchefstroom	D6S1	78.8	cba	162037	edcba	3729.8	dcba	41.2	cba
Potchefstroom	D6S2	79.1	cba	148194	edcba	4188.8	dcba	41.1	cba
Potchefstroom	D6S3	80.6	cba	254167	edcba	5664.5	dcba	41.1	cba
Rustenburg	D1S1	75.2	cba	151273	edcba	2865.4	dcb	44.0	cba
Rustenburg	D1S2	80.5	cba	145972	edcba	2982.3	dcba	44.1	cba
Rustenburg	D1S3	84.1	ba	184722	edcba	3316.9	dcba	44.4	ba
Rustenburg	D2S1	77.3	cba	177431	edcba	3182.1	dcba	43.9	cba
Rustenburg	D2S2	71.6	cba	176805	edcba	3149.0	dcba	44.1	cba
Rustenburg	D2S3	80.7	cba	241435	edcba	3859.1	dcba	44.4	ba
Rustenburg	D3S1	78.6	cba	207407	edcba	2931.6	dcba	43.8	cba
Rustenburg	D3S2	78.8	cba	208056	edcba	2930.8	dcba	43.7	cba
Rustenburg	D3S3	76.2	cba	250463	edcba	4106.9	dcba	44.0	cba
Rustenburg	D4S1	75.4	cba	224421	edcba	2407.4	d	44.0	cba
Rustenburg	D4S2	70.7	cba	245139	edcba	2880.5	dcb	43.5	cba
Rustenburg	D4S3	70.6	cba	296528	edcba	4688.6	dcba	44.2	cba
Rustenburg	D5S1	81.7	cba	266782	edcba	3681.5	dcba	44.4	ba
Rustenburg	D5S2	81.8	cba	260000	edcba	2938.7	dcba	44.5	a
Rustenburg	D5S3	75.0	cba	342824	ba	4389.6	dcba	44.0	cba
Rustenburg	D6S1	82.5	cba	286227	edcba	3199.6	dcba	44.4	ba
Rustenburg	D6S2	74.7	cba	290417	edcba	3984.5	dcba	44.3	cba
Rustenburg	D6S3	68.8	cba	354398	a	3877.0	dcba	44.0	cba
Means		69.9		187908.1		3736.1		42.8	
CV (%)		20.0		23.3		27.0		9.1	
$LSD_{T\ (0.05)}$		33.5		246065		3073.3		3.8	

Means within the column followed by the same letter are not significantly different at 5% probability level

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively.

4.5.2 Locality and density interaction effect on plant population

The highest soybean population of 354 398 plants ha^{-1} was obtained at Rustenburg with planting density of 450 000 plants ha^{-1} at 45 cm inter-row spacing while the lowest population counts of 64 028 plants ha^{-1} was obtained at Potchefstroom with planting density of 200 000 plants ha^{-1} sown at 75 cm inter-row spacing (Table 4.2).

4.5.3 Locality and density interaction effect on grain yield

Yield is the most important characteristic that is determined by the interaction between the genetic potential of a cultivar and the environmental conditions (climate, soil and cultivation practices) under which it is cultivated. Planting density of 400 000 plants ha^{-1} sown at 45 cm inter-row spacing in Potchefstroom gave the highest grain yield of 6 004.1 kg ha^{-1} while planting density of 350 000 plants ha^{-1} sown at 90 cm inter-row spacing in Rustenburg had the lowest yield of 2 407.4 kg ha^{-1} (Table 4.2). Soybean planted at 45 cm between rows thus appears to be the most appropriate in Potchefstroom in terms of the grain yield. Similarly, planting at 45 cm inter-row spacing appears to be the most appropriate at Bethlehem resulting in 400 000 plants ha^{-1} and grain yield of 5 251.2 kg ha^{-1} while at Rustenburg, the most appropriate planting density of 350 000 plants ha^{-1} using 45 cm inter-row spacing gave 4 688.6 kg ha^{-1} seed yield, which was, however, 12.5% and 21.9% less compared to yields at Bethlehem than Potchefstroom, respectively.

4.5.4 Locality and density interaction effect on percentage of grain protein content

Planting density of 400 000 plants ha^{-1} sown at 75 cm inter-row spacing in Rustenburg gave the highest seed protein content of 44.5% while planting density of 200 000 plants ha^{-1} shown at 45 cm inter-row spacing in Potchefstroom had the lowest mean seed protein content of 40.4% (Table 4.2).

4.5.5 Locality and cultivar interaction effect on percent emergence

Soybean cultivar PAN 1500R sown at Potchefstroom had the highest seedling emergence of 89.4% while LS 6240R cultivar sown at Bethlehem had the lowest emergence of 45.6% (Figure 5a). However, PAN 1664R cultivar with the highest seedling emergence of 85.1% at Rustenburg and PAN 1614R with the highest percent seedling emergence of 65.1% at Bethlehem were 4.8% and 27.2%, respectively less than the emergence value obtained at Potchefstroom.

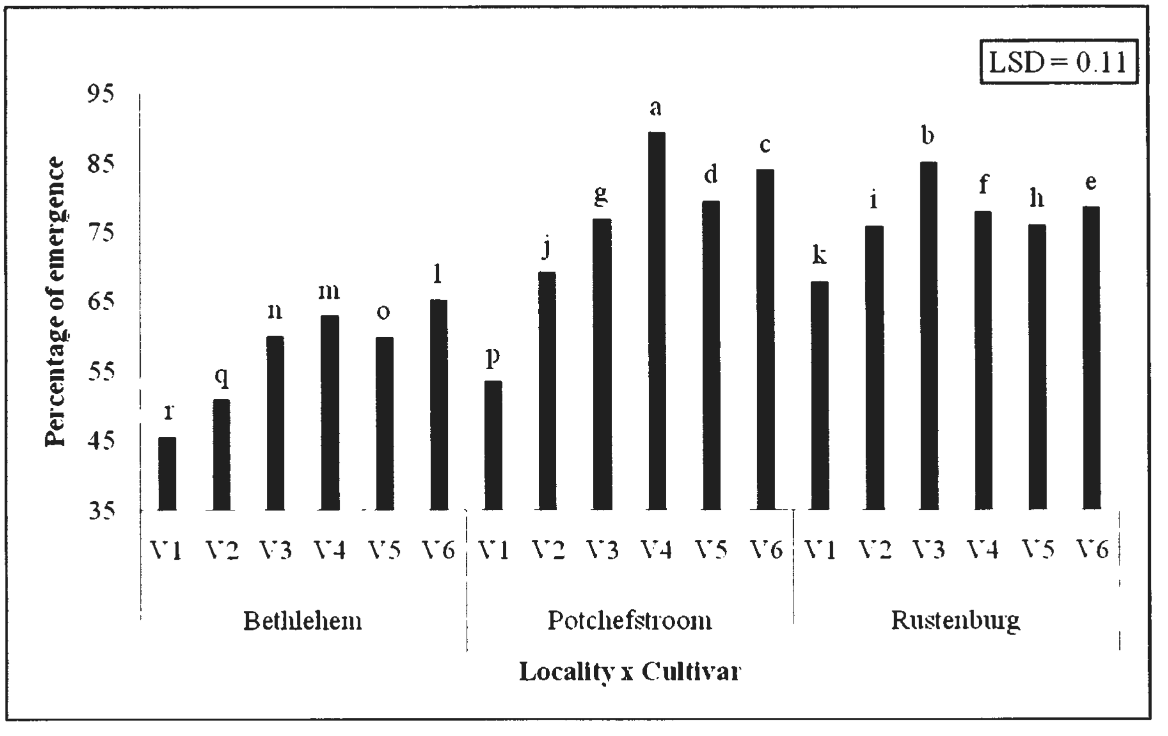

Figure 5a: Locality and cultivar interaction effect on percent emergence

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.6 Locality and cultivar interaction effect on mean plant height

Soybean cultivar PAN 1614R sown at Bethlehem had the highest plant height of 106.9 cm while cultivar LS 6240R sown at Rustenburg gave the lowest plant height of 55.7 cm (Figure 5b). Cultivar PAN 1614R with the highest plant height of 92.9 cm at Potchefstroom and cultivar PAN 1614R with highest plant height of 82.4 cm at Rustenburg were less by 13.1% and 22.9%, respectively-shorter than the plant height obtained for PAN 1614R at Bethlehem.

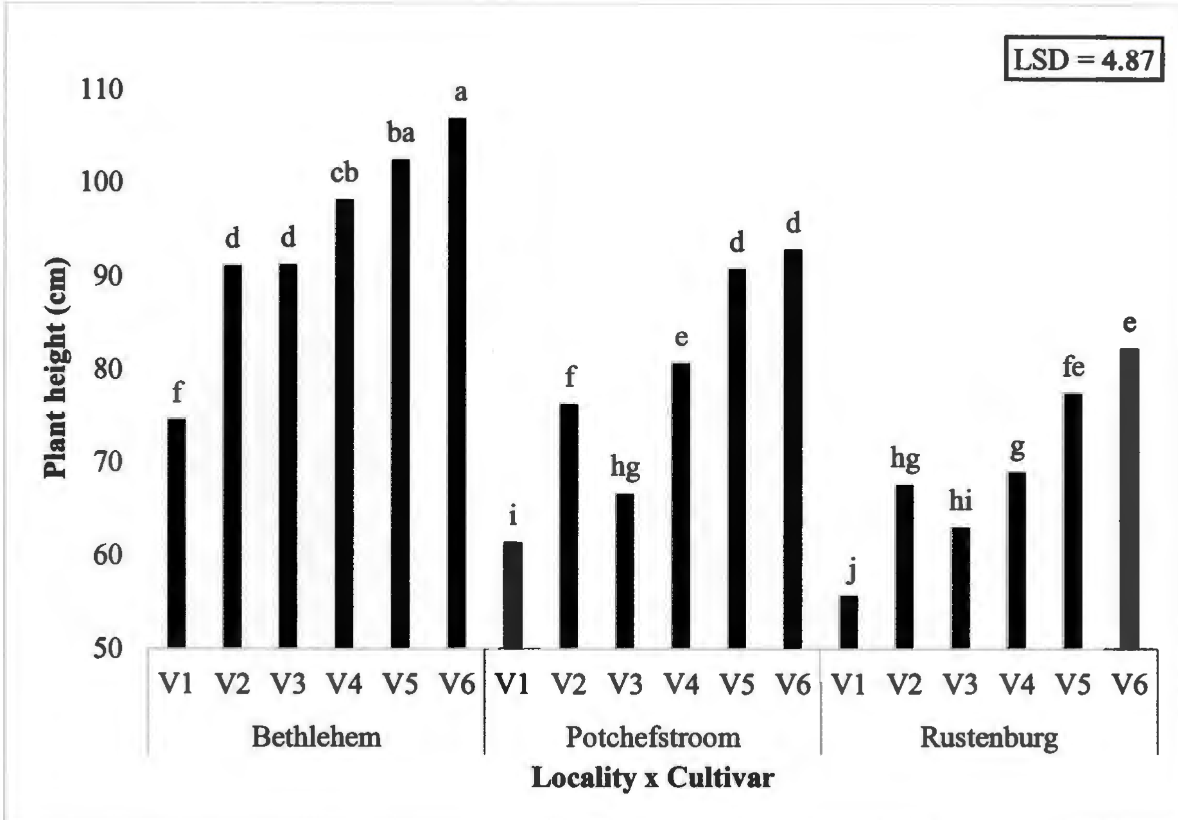

Figure 5b: Locality and cultivar interaction effect on plant height

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.7 Locality and cultivar interaction effect on pod clearance

Soybean cultivar PAN 1614R sown at the three localities had the highest pod clearance while cultivar LS 6240R had the lowest pod clearance across the three localities (Figure 5c). The pod clearance for soybean cultivar PAN 1614R at Bethlehem and Potchefstroom were statistically similar (15.8 cm) but was 32.3% shorter compared to Rustenburg (10.7 cm).

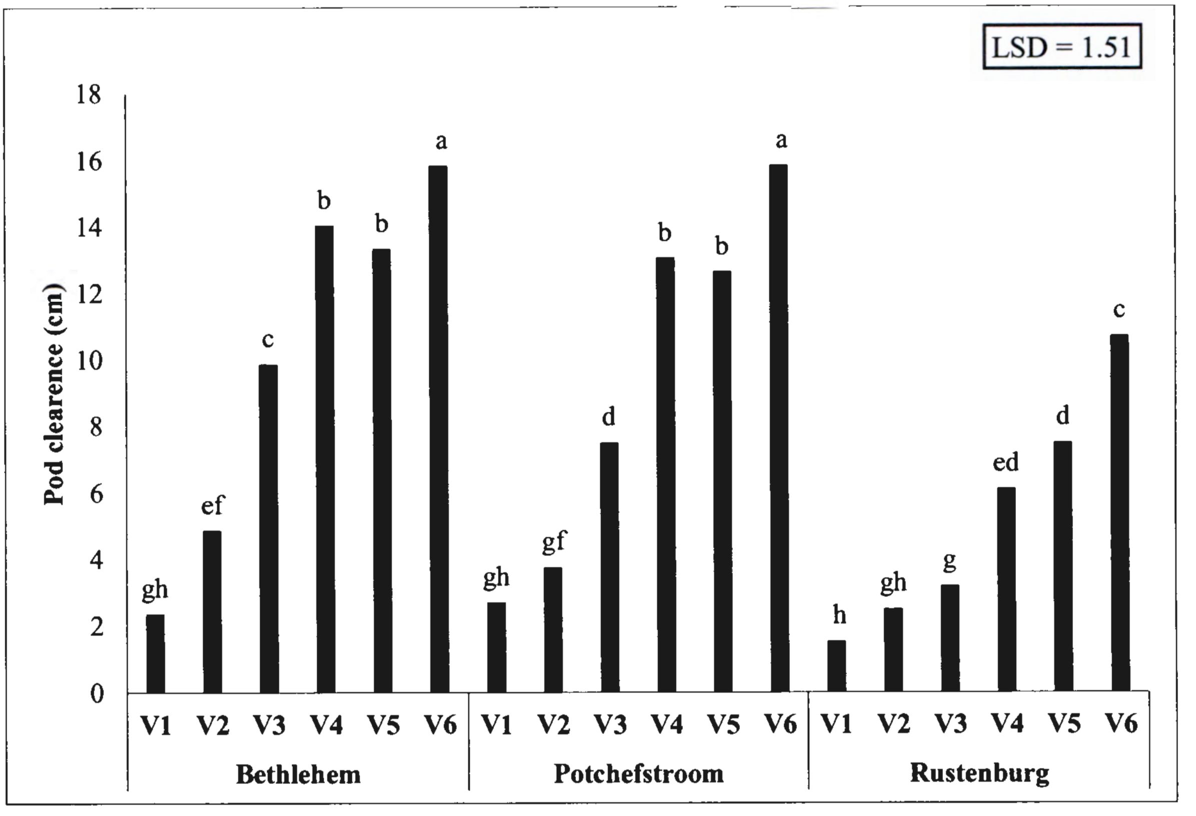

Figure 5c: Locality and cultivar interaction effect on pod clearance

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.8 Locality and cultivar interaction effect on mean weight of 100 seeds

Soybean cultivar LS 6240R sown at Rustenburg had the highest 100-seed weight of 24.2 g while cultivar PAN1614R, sown at Bethlehem had the lowest weight of 15.0 g (Figure 5d). The highest 100-seed weights for soybean cultivar LS 6240R obtained at Potchefstroom and Bethlehem were 11.6% and 21.1%, respectively-lower than the 100-seed weight obtained at Rustenburg.

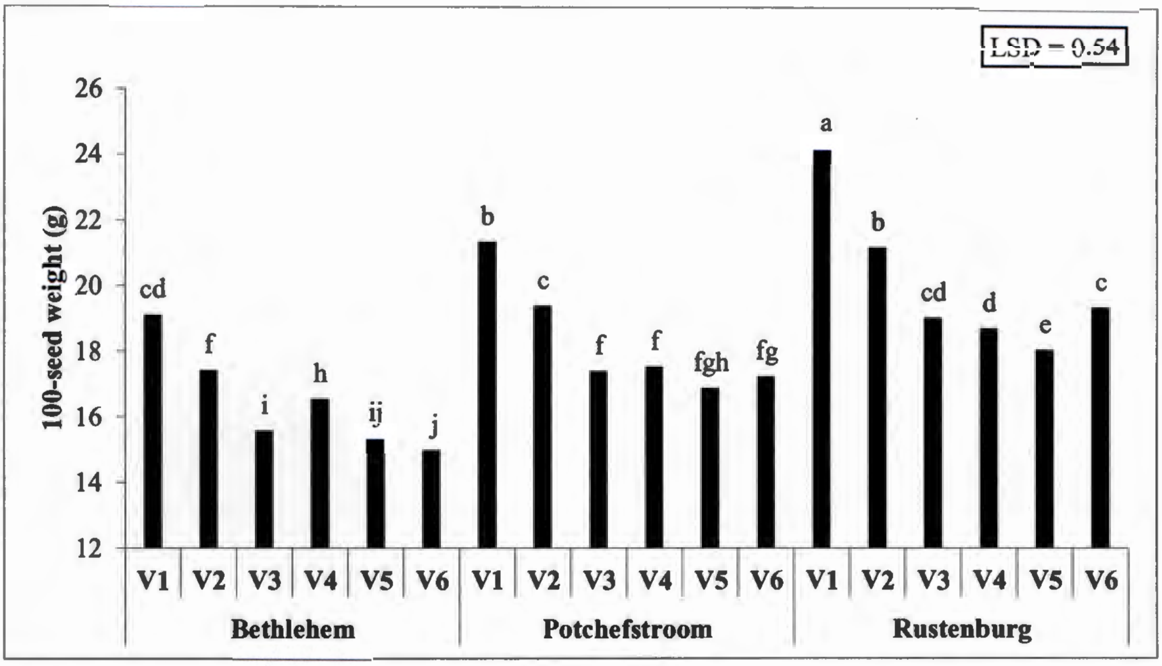

Figure 5d: Locality and cultivar interaction effect on weight of 100 seeds

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.9 Locality and cultivar interaction effect on seed moisture percentage

The highest seed moisture content of 12.4% was obtained in soybean cultivar PAN 1500R sown at Rustenburg while the lowest seed moisture content of 10.2% was obtained from the same soybean cultivar sown at Potchefstroom (Figure 5e). PAN 1614R cultivars with the highest seed moisture content of 12.2% at Bethlehem and PAN 1664R with the highest seed moisture content of 11.1% at Potchefstroom had 1.6% and 10.5%, respectively, less seed moisture content than the highest value obtained at Rustenburg.

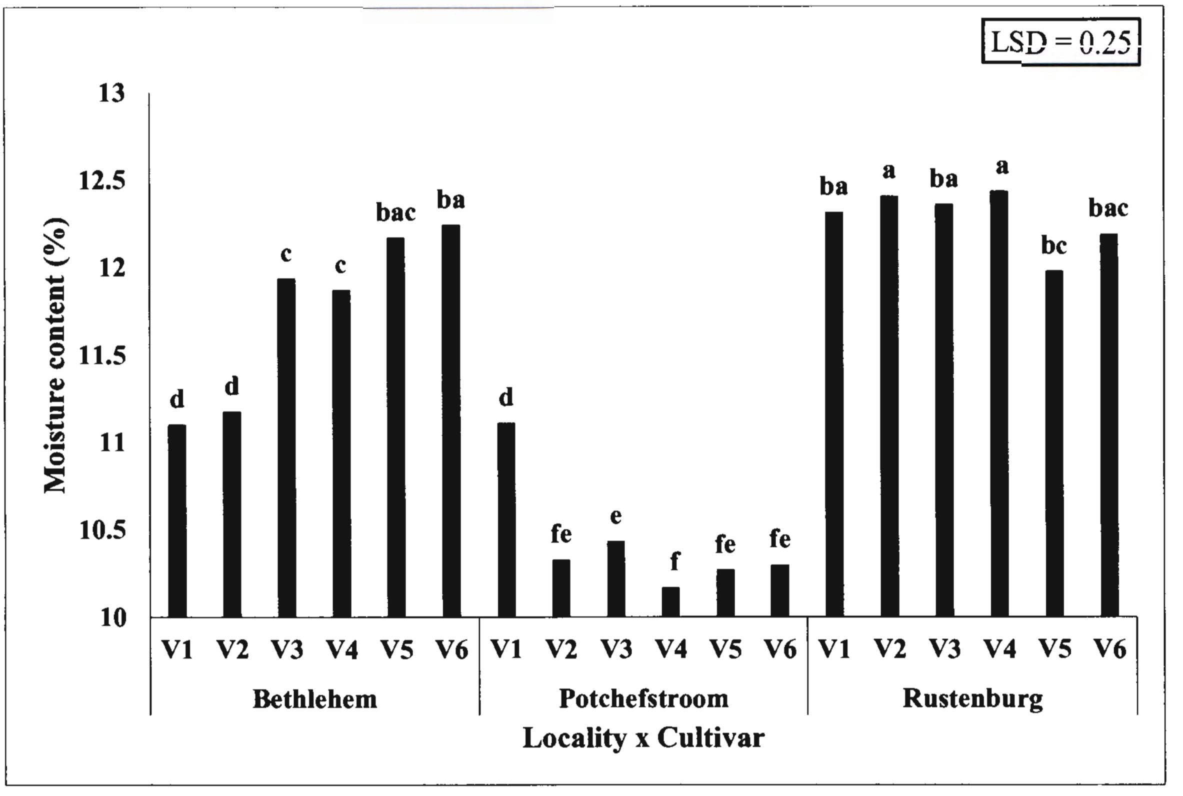

Figure 5e: Locality and cultivar interaction on seed moisture percent

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.10 Locality and cultivar interaction effect on grain yield

Soybean cultivar PAN 1500R sown at Potchefstroom gave the highest grain yield of 4 748.7 kg ha^{-1} while cultivar LS 6240R sown at Rustenburg gave the lowest grain yield of 2 587.0 kg ha^{-1} (Figure 5f). The highest grain yields for cultivars LS 6240R (4 493.7 kg ha^{-1} at Bethlehem) and LS 6164R (4 044.9 kg ha^{-1} at Rustenburg) were, respectively 5.4% and 14.8%, less than at Potchefstroom.

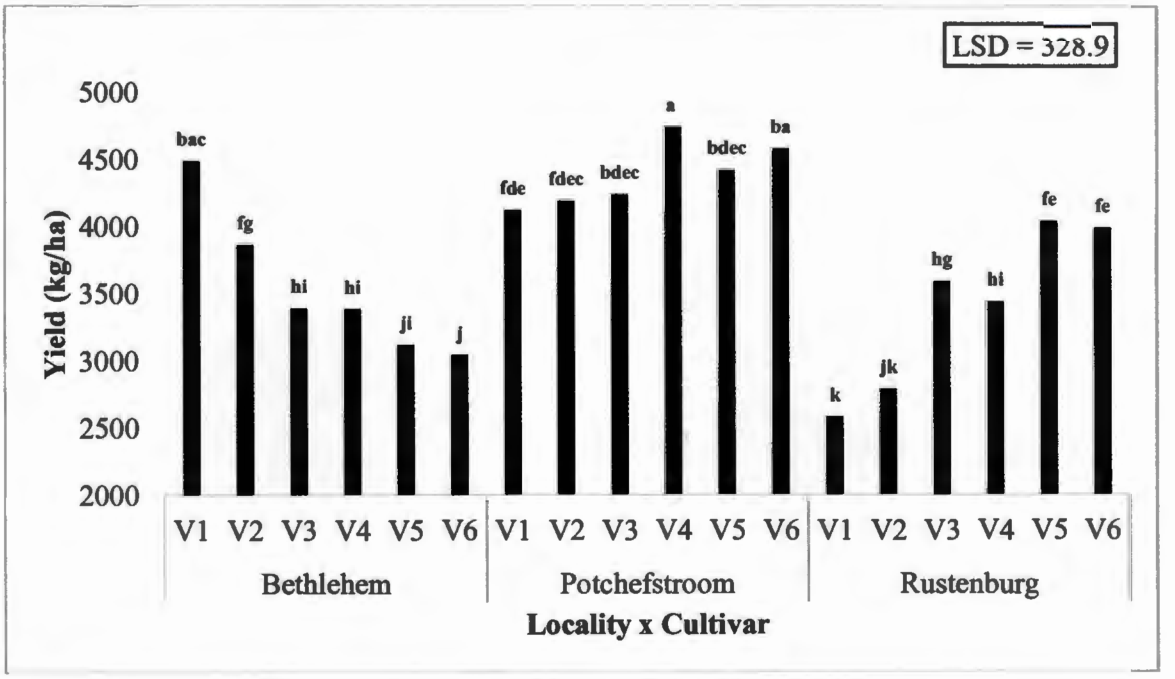

Figure 5f: Locality and cultivar interaction on grain yield

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.11 Locality and cultivar interaction effect on percent seed protein content

Soybean cultivar PAN 1500R sown at Rustenburg gave the highest protein content of 45.3% while the cultivar PAN 1614R sown at Potchefstroom gave the lowest protein content of 39.7% (Figure 5g). PAN 1500R had the highest protein content of 42.7% at Bethlehem while PAN 1500R had highest protein content of 42.5% at Potchefstroom but both represented 5.7% and 6.2%, respectively, less seed protein content than at Rustenburg.

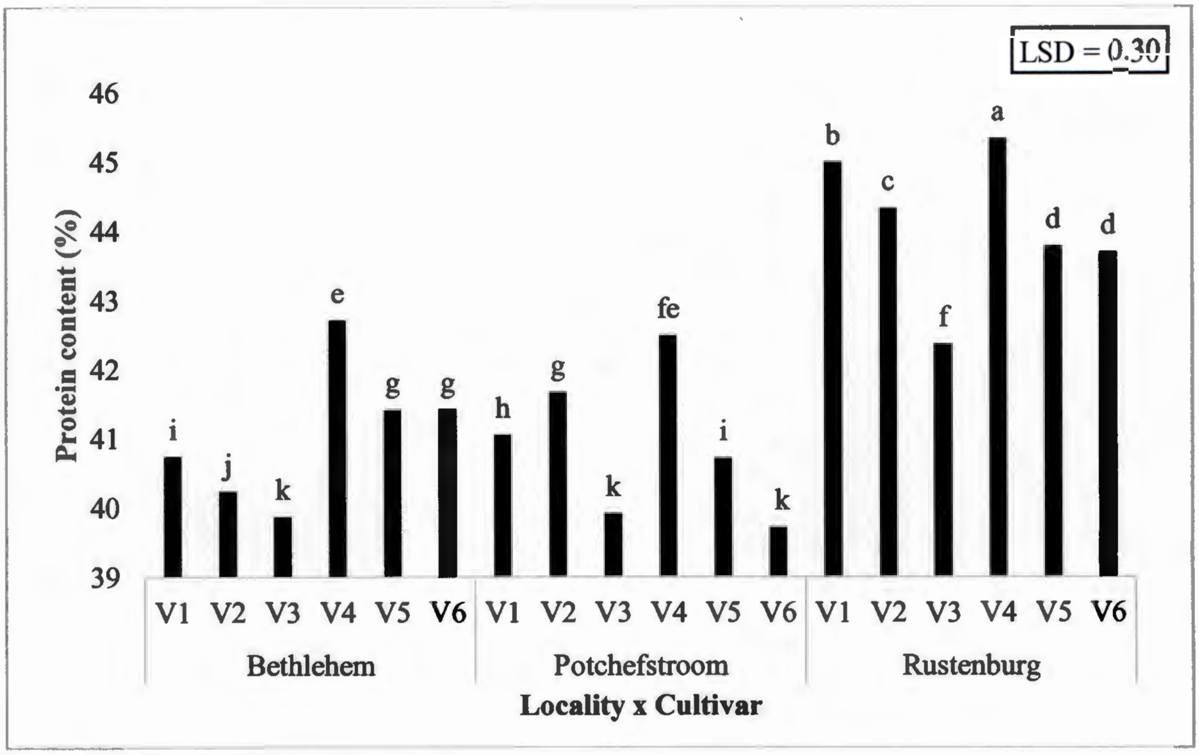

Figure 5g: Locality and cultivar interaction percent protein content

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.5.12 Locality and cultivar interaction effect on percent seed oil content

Soybean cultivar LS 6240R sown at Potchefstroom had the highest seed oil content of 21.9% while the cultivar PAN 1664R sown at Bethlehem had the lowest seed oil content of 19.3% (Figure 5h). The highest seed oil content of 21.0% from soybean cultivar LS 6240R at Bethlehem and 20.6% from cultivar PAN 1664R at Rustenburg were 4.1% and 5.9%, respectively, less than the highest seed oil content at Potchefstroom.

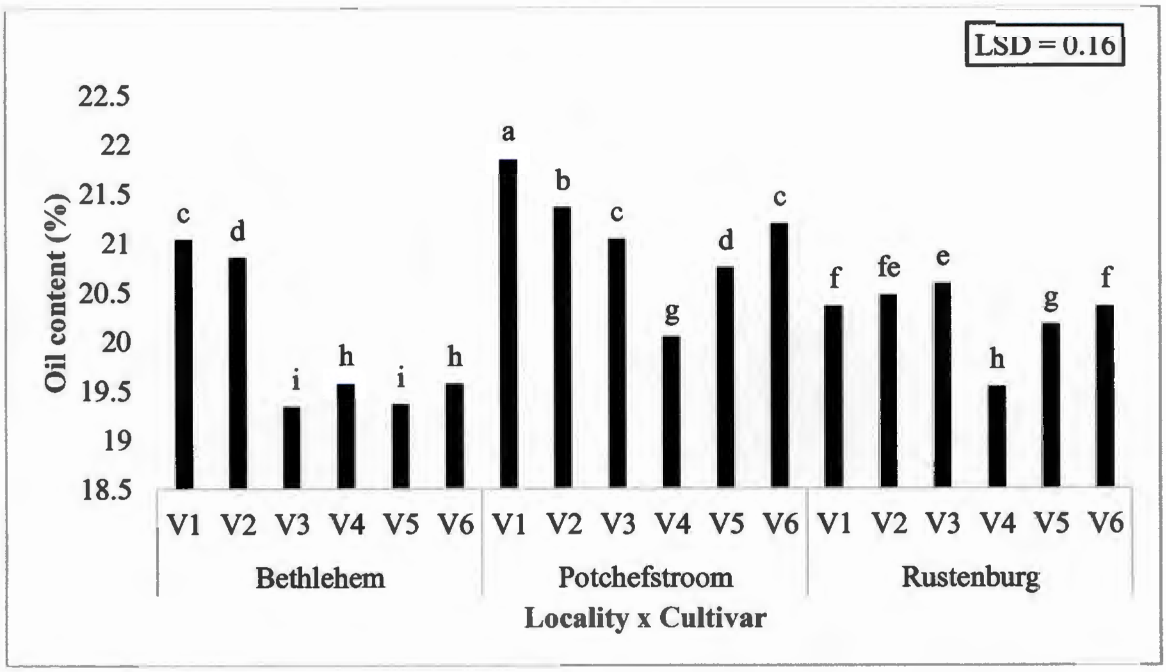

Figure 5h: Locality and cultivar interaction on percentage oil content

V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

4.4.13 Density and cultivar interaction effect on plant height

Soybean cultivar PAN 1614R sown at planting 400 000 plant ha^{-1} and 45 cm inter-row spacing (density D5S3) gave the highest plant height of 106.6 cm while cultivar LS 6240R sown at density 350 000 plants ha^{-1} and 90 cm inter-row spacing (D4S1) gave the lowest plant height of 61.4 cm (Table 4.3).

4.5.14 Density and cultivar interaction effect on grain yield

Soybean cultivar PAN 1500R sown at a density of 400 000 plants ha^{-1} and 45 cm inter-row spacing (D5S3) gave the highest grain yield of 5 820.2 kg ha^{-1} while cultivar PAN1664R sown at density 200 000 plants ha^{-1} and 90 cm inter-row spacing (D1S1) gave the lowest grain yield of 2 509.6 kg ha^{-1} (Table 4.3).

Table 4.3: Plant density x cultivar interaction effects on plant height (H) and Grain Yield (Y)

Density	Cult	Pl[redacted]		[redacted]	
D1S1	V1	63.4	ba	3124.6	cba
D1S1	V2	88.3	ba	3495.6	cba
D1S1	V3	70.0	ba	2509.6	c
D1S1	V4	82.1	ba	3103.1	cba
D1S1	V5	94.7	ba	2986.3	cba
D1S1	V6	90.7	ba	3291.6	cba
D1S2	V1	61.5	b	2961.0	cb
D1S2	V2	82.1	ba	3177.6	cba
D1S2	V3	72.1	ba	3152.4	cba
D1S2	V4	80.3	ba	3185.2	cba
D1S2	V5	83.4	ba	2625.8	cb
D1S2	V6	97.0	ba	3993.1	cba
D1S3	V1	61.9	b	4084.4	cba
D1S3	V2	80.3	ba	3991.8	cba
D1S3	V3	72.8	ba	3665.7	cba
D1S3	V4	79.2	ba	3612.6	cba
D1S3	V5	85.5	ba	4663.7	cba
D1S3	V6	101.4	ba	3681.8	cba
D2S1	V1	65.7	ba	3144.5	cba
D2S1	V2	80.9	ba	3423.6	cba
D2S1	V3	75.5	ba	4105.9	cba
D2S1	V4	91.7	ba	3400.2	cba
D2S1	V5	101.7	ba	3432.0	cba
D2S1	V6	94.0	ba	2869.6	cb
D2S2	V1	63.5	ba	2974.4	cba
D2S2	V2	81.3	ba	3171.6	cba
D2S2	V3	74.6	ba	3836.6	cba
D2S2	V4	89.4	ba	3125.1	cba
D2S2	V5	94.8	ba	3767.8	cba
D2S2	V6	93.7	ba	3271.2	cba
D2S3	V1	62.1	b	4900.9	cba
D2S3	V2	75.4	ba	3478.7	cba
D2S3	V3	74.0	ba	4064.7	cba
D2S3	V4	83.8	ba	5023.4	cba
D2S3	V5	87.9	ba	4496.2	cba
D2S3	V6	93.8	ba	4531.7	cba
D3S1	V1	67.1	ba	3307.6	cba
D3S1	V2	79.6	ba	3176.6	cba
D3S1	V3	76.4	ba	3818.9	cba
D3S1	V4	89.3	ba	2895.9	cb
D3S1	V5	89.5	ba	3175.7	cba
D3S1	V6	99.4	ba	3124.4	cba
D3S2	V1	69.3	ba	3665.4	cba
D3S2	V2	73.9	ba	3307.7	cba
D3S2	V3	71.1	ba	2783.7	cb
D3S2	V4	83.1	ba	3287.6	cba
D3S2	V5	94.8	ba	3417.8	cba
D3S2	V6	86.0	ba	3395.0	cba
D3S3	V1	69.6	ba	5401.9	ba
D3S3	V2	83.1	ba	4838.7	cba
D3S3	V3	77.2	ba	4659.8	cba
D3S3	V4	82.5	ba	4790.7	cba
D3S3	V5	86.7	ba	4141.2	cba
D3S3	V6	94.9	ba	4453.1	cba
D4S1	V1	61.4	b	3203.6	cba
D4S1	V2	72.7	ba	2573.6	cb
D4S1	V3	75.1	ba	3106.5	cba
D4S1	V4	87.1	ba	3149.2	cba
D4S1	V5	101.6	ba	3453.7	cba
D4S1	V6	97.4	ba	3238.1	cba
D4S2	V1	66.0	ba	2730.4	cb
D4S2	V2	79.9	ba	3083.2	cba
D4S2	V3	81.9	ba	2999.1	cba
D4S2	V4	85.0	ba	3717.5	cba
D4S2	V5	97.5	ba	3519.0	cba
D4S2	V6	93.7	ba	3467.4	cba
D4S3	V1	68.0	ba	4716.4	cba
D4S3	V2	78.4	ba	4388.8	cba
D4S3	V3	72.2	ba	4211.8	cba
D4S3	V4	86.0	ba	4748.6	cba
D4S3	V5	89.0	ba	4704.8	cba
D4S3	V6	96.5	ba	5084.2	cba

D5S1	V1	66.1	ba	4024.7	cba
D5S1	V2	81.6	ba	3143.6	cba
D5S1	V3	78.4	ba	3440.1	cba
D5S1	V4	90.3	ba	3545.7	cba
D5S1	V5	97.8	ba	3771.1	cba
D5S1	V6	97.1	ba	3618.1	cba
D5S2	V1	66.1	ba	3403.7	cba
D5S2	V2	81.9	ba	3115.0	cba
D5S2	V3	76.6	ba	3375.5	cba
D5S2	V4	88.1	ba	3064.2	cba
D5S2	V5	97.0	ba	3339.1	cba
D5S2	V6	100.7	ba	3649.1	cba
D5S3	V1	64.6	ba	4854.4	cba
D5S3	V2	79.8	ba	5077.6	cba
D5S3	V3	78.9	ba	5022.0	cba
D5S3	V4	88.1	ba	5820.2	a
D5S3	V5	93.9	ba	5120.0	cba
D5S3	V6	106.6	a	5161.9	cba
D6S1	V1	67.3	ba	3292.0	cba
D6S1	V2	88.4	ba	3447.2	cba
D6S1	V3	80.7	ba	4019.5	cba
D6S1	V4	86.8	ba	3357.4	cba
D6S1	V5	100.0	ba	3283.9	cba
D6S1	V6	99.6	ba	2927.9	cb
D6S2	V1	65.9	ba	3539.8	cba
D6S2	V2	79.2	ba	4054.0	cba
D6S2	V3	79.5	ba	3428.7	cba
D6S2	V4	86.4	ba	3899.1	cba
D6S2	V5	90.2	ba	3794.4	cba
D6S2	V6	102.7	ba	3980.1	cba
D6S3	V1	70.1	ba	4501.1	cba
D6S3	V2	84.2	ba	3984.6	cba
D6S3	V3	71.7	ba	4316.0	cba
D6S3	V4	81.7	ba	4338.1	cba
D6S3	V5	93.2	ba	4414.3	cba
D6S3	V6	94.9	ba	4318.5	cba
Means		82.9		3736.1	
Cv (%)		32.1		36.7	
LSD $_{T (0.05)}$		43.2		2845.2	

Means within the column followed by the same letter are not significantly different at 5% probability level

D1, D2, D3, D4, D5 and D6 implies 200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plants/ha density, respectively while S1, S2 and S3 implies 90 cm, 75 cm and 45 cm inter-row spacing, respectively. V1 = LS 6240 R, V2 = PAN 1454 R, V3 = PAN 1664 R, V4 = PAN 1500 R, V5 = LS 6164 R, V6 = PAN 1614 R

CHAPTER 5

DISCUSSION

5.1 The percentage emergence of the different soybean cultivars

Seed germination is a natural biological process for plants during which some quantitative and qualitative nutrient changes occur within the seed depending on the type of vegetable, the seed cultivar and germination conditions (Reihaneh & Jamuna, 2007). Seedling emergence following sowing depends on the prevailing climatic conditions, seed quality and soil characteristics at each planting region. As observed in this study, seedling emergence for the different soybean cultivars was better and higher at Rustenburg than Potchefstroom and Bethlehem because of the warm temperature and adequate soil moisture, which favour the emergence process. However, increase in temperature during grain filling had been reported to exert a negative effect on seedling emergence and plant vigour of commercial soybean cultivars in following season, especially if it occurred during the first 10 days of seed filling (Peske *et al.*, 2014). The soybean cultivars that germinated well under warm regions typical of Rustenburg performed poorly in cold regions typical of Bethlehem due to unfavourable germination conditions (Senaratna & McKersie, 1983). A similar observation was reported by Wang and Shannon (1999) for soybean cultivars germination in areas with cool or low temperatures. Soybean cultivar PAN 1500R that had higher percent protein content in its cotyledons than other cultivars attained higher germination percentage while soybean cultivar with less protein in its cotyledons, such as LS 6240R, may easily die during the germination process due to low energy to support growth (Liebenberg, 2012).

Results from this study also suggest that seedling emergence for the different soybean cultivars vary across different plant densities at each locality where in 300 000 plants ha^{-1} obtained at 45 cm inter-row spacing at Potchefstroom had the best emergence values because of better environment conditions than the other two localities. The least percent seedling emergence obtained at 450 000 plants ha^{-1} when seeds were sown at 90 cm inter-row spacing at Bethlehem was possibly due to a marginally reduced seed quality even with the necessary capacity to absorb nutrients, water and other resources required for seed to emergence and better growth (Chen *et al.*, 2014). Seedling emergence at Potchefstroom was highest with PAN 1500R cultivar possibly due to more favourable environmental conditions combined with the high quality seeds, which favoured emergence and better growth (Chen *et al.*, 2014).

5.2 Plant height of the different commercial soybean cultivars

Results of recent soybean cultivar evaluation trials showed that early maturity cultivars are shorter than the late maturity cultivars (ARC, 2013); and are also significantly influenced by latitude or altitude (Liebenberg, 2012). The reportedly higher plant height for the different commercial soybean cultivars planted at 450 000 plants ha^{-1} at Bethlehem in this study may be due to the excess number of plants per row (203 plants) resulting in competition for light and increase in length to acquire or access light (Chen *et al.*, 2014) while plants at a density of 200 000 plants ha^{-1} with only 75 plants per row had less competition for light. Khalil (1993) similarly reported that plant height increased with increasing population density as observed in this study while increase taller plants were observed across the three localities at higher population density.

5.3 Pod clearance of the different commercial soybean cultivars

The pod clearance of the different commercial soybean cultivar has an impact on harvest ability of the crop. It represents an important characteristic that is often considered while deciding on cultivar selection and where to plant because of the relationship between pod clearance and relative length of the growing season (ARC, 2013). Cultivars with a relatively short growth duration (LS 6240R and PAN 1454R) have a low pod-clearence than cultivars with longer growth duration (LS 6164R and PAN 1614R). The much narrower inter- and intra-row spacing (450 000 plants ha^{-1} and 45 cm) for the different cultivars as reported in this study resulted in significantly taller pod clearance. The relatively higher pod clearance at Bethlehem than Rustenburg and Potchefstroom is possibly attributed to the cooler zone and higher altitude thus favouring the plant growth for a much longer duration and providing taller pod clearance than those under hot environment at low altitude (Liebenberg, 2012).

Pod clearance at a density of 450 000 plants ha^{-1} is similarly higher due to the excess number of plants per row (203 plants) resulting in plants competing for light to grow and consequently the pods are formed at an elevated height. On the contrary, the density of 200 000 plants ha^{-1} with only 75 plants per row may have experienced limited or no competition for light (Chen *et al.*, 2014), and may also depend on the nature of the variety (ARC, 2015).

5.4 Number of days to flowering

The results of this study suggest that soybean flowers faster in places where the temperature is warmer than in places where the temperature is cold. The number of days to 50% flowering was shorter in Rustenburg because it has warm temperatures while Bethlehem experienced cold temperatures that resulted in prolonged number of days. This agrees with findings reported by Andric *et al.* (2012). The process of flowering in soybean is influenced by a number of qualitatively determined traits such as the genetic composition of the each variety (Yamada *et al.*, 2012) and environmental factors such as day light days and light intensity. Hence, soybean varieties with determinate growth habit in this study (LS 6240R, PAN 1664R, LS 6164R) commenced flowering much earlier than the indeterminate cultivars (PAN 1454R, PAN 1500R, PAN 1614R).

5.5 Number of days to physiological maturity

The maturity of soybean cultivars is related to the number of days to flowering and also type of cultivars (Liebenberg, 2012). The finding in the current study that the different soybean plants attained 50% physiological maturity much earlier at Rustenburg possibly because of the warmer conditions is in agreement with earlier findings reported by Kato *et al.* (2015). The Duration to 50% physiological maturity across all planting densities for LS 6240R cultivar was the shortest since it belongs to the early physiological maturity group while PAN 1614R had the longest mean number of days as it belongs to the late physiological maturity group (ARC, 2015).

5.6 Number of days to harvest maturity

It is always important that early harvesting of soybean grains is carried out regardless of the planting objectives. Cultivar LS 6240R offers better advantage considering this quality because it belongs to the short maturity duration group (ARC, 2014). Hence, in terms of farmers' selection preference as observed during this study PAN 1614R cultivar is not suitable because it belongs to long maturity group resulting in longer number of days to harvest (ARC, 2015).

5.7 Population of commercial soybean cultivars at harvest

High and proportional distribution of the number of plants (i.e. plant population) within an area during soybean production, as alluded to by Ramesh & Ramprasad (2014) showed that the practices used were effective and contributes significantly to the increase in the production and productivity of plants. The extent and success of seedling emergence in planted soybean seeds depend on cultivar, seed quality, planting locality and plant density (Monsanto, 2015). In this study, planting density of 450 000 plants ha^{-1} using 90 cm inter-row spacing was more suitable for the maintenance of the number of plants that emerged until harvesting at Rustenburg because of better and more favourable environmental conditions than either Potchefstroom or Bethlehem. The least number of soybean plants using 200 000 plants ha^{-1} and 75 cm space between rows obtained at Potchefstroom was possibly due to the high competition for nutrients by soybean plants (Senaratna & McKersie, 1983). Nevertheless, the choice of appropriate plant density may help to reduce the competition for nutrients by the growing soybean since plants are often very sensitive and may die if nutrients are limiting. However, too low density could also results in wastage of space on the field that may create opportunity for weed invasion. Of the six soybean cultivars, PAN 1500R had the highest percentage plants population at harvest than any other cultivars and also had the highest percentage seedling emergence across all the three localities. This is in agreement with the results of an earlier study reported by Liebenberg (2012).

5.8 Variation in 100-seeds weight of the different commercial soybean cultivars

Soybean seed develops and increases in mass up to the physiological ripening stage. The seeds are typically round to oval in shape with a mass between 12 g to 25 g per 100 seeds (ARC, 2014). In this study, the 100 seeds weight obtained across all localities and cultivars ranged from 15 g to 24.2 g. Moisture stress during the pod filling stage can result in the formation of small-size seeds while large seeds obtained during plant growth are an indication of sufficient moisture (Smit, 2000). The higher 100-seed weight obtained at Rustenburg across all cultivars suggests that the different commercial soybean cultivars received enough water and the adequate nutrients during the physiological grain filling and ripening stages compared to cultivars from Bethlehem and Potchefstroom (ARC, 2015). The highest 100-seed weight reported with LS 6240R cultivar across all localities and planting densities suggests that is it more physiologically able to absorb water and nutrients during the seed formation stage. In contrast, soybean cultivars at Bethlehem experienced water stress during the physiological maturity stage that exerted a depressive influence on the recorded seed weight. Grain SA (2015) reported that the provision of sufficient moisture is an important management provision that is critical to soybean production. The best performance of soybean cultivar LS 6240R at Rustenburg was therefore attributed to the suitable environmental conditions that favoured all physiological processes and proper pod maturation, which were unavailable including cultivar genetic characteristic and variation at Bethlehem for PAN 1614R (Boote *et al*, 2001).

5.9 The seed moisture content of the different commercial soybean cultivars

The general requirement for high quality soybean seeds is that moisture content after harvest from the field must be kept at or below 14% so as to prevent susceptibility to mechanical damage and for a safe storage (Peske *et al.*, 2014). However, it is recommended that harvesting of soybean be accomplished when the seeds are in the range of 15-18% moisture content in order to minimize field deterioration since high percentage moisture content will affect grain yield (Peske *et al.*, 2014). Soybean grains from Rustenburg had average moisture content of about 12.4% across all cultivars and therefore considered adequate for storage while seed moisture content of 10.4% across all cultivars at Potchefstroom is safe and adequate for storage since the value is below 14% (OMAFRA, 2016).

5.10 Grain yield of the different commercial soybean cultivars

According to the grain yield results obtained in this research, the Potchefstroom environmental conditions (climate, soil and other cultivation practices) appeared to be the most favourable than Bethlehem and Rustenburg for the growth and performance of the six commercial soybean cultivars. Results of similar investigation conducted during 2010/2011 and 2011/2012 in the National Soybean Cultivar Trial at 19 localities using 23 cultivars showed that Potchefstroom had higher mean grain yield of 3 765 kg ha^{-1} than any other localities (ARC, 2013). PAN 1500R cultivar grown at a density of 400 000 plants ha^{-1} and 45 cm inter-row spacing at Potchefstroom performed best where the soil conditions are suitable (sandy clay loam textural class) thereby favouring excellent growth, water and nutrients uptake and consequently, promoting plant physiological processes of maturation. The most appropriate cultivar at Bethlehem was LS 6240R with planting density of 300 000 plants ha^{-1} and 45 cm inter-row spacing while at Rustenburg, the most appropriate cultivar was LS 6164R with planting density 400 000 plants ha^{-1} and 45 cm inter-row spacing. However, the clayey textural nature of soil and relatively high soil pH value of 7.89 are not favourable for cultivar LS 6240R at Rustenburg possibly because of the early physiological maturity nature of cultivar. The best performance of PAN 1500R cultivar at Potchefstroom when planted at a density of 400 000 plants ha^{-1} with seeds sown at 45 cm inter-row spacing because the cultivar belongs to medium physiological maturity group (ARC, 2013) while cultivar PAN1664R grown at density 200 000 plants ha^{-1} and 90 cm inter-row spacing did not perform well possibly because of variation in the cultivar's genetic characteristic and its early physiological maturity.

5.11 The protein content of the different commercial soybean cultivars

The warm temperatures experienced in Rustenburg environment exert positive influence on the percentage soybean protein content. The range of 40.4 to 44.5% for the seed protein content across all localities, cultivars and planting densities obtained in this study were similar to the range reported by Wilson (2004) from a collection in the United States Department of Agriculture. The low percent seed protein content in soybean grains obtained from Potchefstroom may be as a result of poor nitrogen fixation throughout the growth season and high temperature during the reproductive growth stage (Robinson & Conley, 2014). The density of 400 000 plants ha^{-1} sown at 90 cm inter-row spacing had higher plants population that in turn causes stress, which culminated in 15% lower seed protein content about than at a density of 250 000 plants ha^{-1} grown at 90 cm inter-row spacing because of limited competition that may cause stress on the plants to increase the level of protein (Kato *et al.*, 2015). Furthermore, soybean density of 400 000 plants ha^{-1}grown in Rustenburg (warm temperature) obtained when seeds were sown at 75 cm inter-row spacing contains higher concentration of plant population which causes plant stress that culminates in increase grain protein content (Wolf *et al.*, 1982).

5.12 The oil content of the different commercial soybean cultivars

Clemente & Cahoon (2009) revealed that plant microenvironment such as the location of seeds on soybean plant can impact on carbon flux during embryogenesis thereby resulting in pods positioned at the top of soybean plants to have seeds with higher percentage protein but lower oil contents than those positioned at the bottom parts. Hence, soybean grown at Potchefstroom had more percentage oil due to lower percent protein obtained. Soybean plant grown in Bethlehem had high number of pods positioned at the top of plant as observed in the current study and consequently, had higher percent seed oil content. The highest percent seed oil content for LS 6240R soybean cultivar grown at Potchefstroom may be attributed to its innate genetic characteristic as a medium physiological maturity cultivar and environmental conditions. Wilson (2004) reported that the oil content across several genotypes within the United States Department of Agriculture soybean germplasm collection ranged from 8.1 to 27.9%. The seed oil content obtained from the current study ranged from 16.6 to 24.2% across all localities, cultivars and planting densities, which were within the values reported by Wilson (2004) and DAFF (2014). The planting density of commercial soybean had marginal effect on percent oil content.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Six round-up ready (R) soybean cultivars were planted at three localities using three different row spacing at six plant densities as improved agronomic practices to evaluate their growth and productivity. Treatments consisted of six plant densities (200 000, 250 000, 300 000, 350 000, 400 000and 450 000 plants ha^{-1}) planted at three inter-row spacing (90cm, 75cm and 45cm) for the different soybean cultivars. The trial at each locality was laid out in a split-split plot arrangement and fitted into a randomized complete block design (RCBD). Growth and yield data as well other yield attributes such as 100-seed weight, oil, and protein data, and appropriate plant density that contribute to increase soybean productivity for farmers and the industry were determined. Key findings from the current study are summarized below:

i. Rustenburg was the most appropriate locality with a maximum seedling emergence of 76.9% for all six soybean cultivars. The significant locality x plant density interaction effect on percent seedling emergence at Potchefstroom revealed the highest emergence (85.5%) at a density of 300 000 plants ha^{-1} and 45 cm inter-row spacing particularly for cultivar PAN 1500R.

ii. The LS 6240R cultivar planted at Rustenburg attained 50% flowering, physiological and harvest maturity in 53,125 and 137 days, respectively across all planting densities and localities because of its early physiological maturity.

iii. The highest mean plant height of 106.9 cm was obtained across the different soybean cultivars with taller plants obtained at Bethlehem than Rustenburg and Potchefstroom. The tallest plants were obtained with PAN 1614R cultivar sown at a density of 400 000 plants ha^{-1} and 45 cm inter-row spacing.

iv. Soybean pod clearance was highest (15.8 cm) in PAN 1614R cultivar grown at Bethlehem at a planting density of 450 000 plants ha^{-1} and 45 cm inter-row spacing allowing for mechanical harvesting.

v. Planting density of 450 000 plants ha^{-1} sown at 45 cm inter-row spacing at Rustenburg gave the highest mean number of 354 398 plants ha^{-1} at harvest.

vi. The highest grain yield of 6 004.1 kg ha^{-1} for cultivar PAN 1500R was obtained at plant density 400 000 plants ha^{-1} with 45 cm inter-row spacing in Potchefstroom. In Rustenburg, the highest grain yield of 4 688.6 kg ha^{-1} was obtained from cultivar LS 6164R when planted at a density of 350 000 plants ha^{-1} using 90 cm inter-row spacing. The highest grain yield of 5 251.2 kg ha^{-1} at Bethlehem was obtained from cultivar LS 6240R when planted at a density of 400 000 plants ha^{-1} with 45 cm inter-row spacing.

vii. The LS 6240R cultivar gave the highest mean 100-seed weight of 24.2 g across all planting densities at Rustenburg.

viii. The percent moisture content at harvest was higher in PAN 1500R cultivar seed (12.4%) grown at Rustenburg while seed from PAN 1500R cultivar had moisture percentage of 10.2% across all plant densities. This moisture level is suitable for long-term storage of the soybean.

ix. The seed protein content of 45.3% from LS 6164R cultivar planted at a density of 400 000 plants ha^{-1} using 75 cm inter-row spacing at Rustenburg represented the highest value across all cultivars and planting densities (Appendix 13).

x. The 21.9% seed oil content of soybean cultivar LS 6240R grown at Potchefstroom using planting density of 350 000 plants ha^{-1} with 75 cm inter-row spacing was highest across all cultivars and planting densities (Appendix 13).

In conclusion, when soybean production is solely for grain yield (i.e. no specific consideration for protein and oil) it is recommended that PAN 1500R cultivar be selected at Potchefstroom while LS 6164R and LS 6240R cultivars are considered appropriate for Rustenburg and Bethlehem localities, respectively. Based on these preliminary findings from one year field data, it is obvious that the optimum plant density and inter-row spacing required to obtain high grain yield as well as seed oil and protein contents for the six commercial soybean cultivars vary greatly across the three localities. For maximum grain yield production, planting of seeds at density of 400 000 plants ha^{-1} using 75 cm distance between rows and 350 000 plants ha^{-1} using 45 cm row spacing is recommended at Potchefstroom and Rustenburg, respectively while planting at 400 000 plants ha^{-1} using 45 cm row spacing is recommended at Bethlehem (Appendix 14). Density of 400 000 plants ha^{-1} using 90 cm row spacing at Potchefstroom, 400 000 plants ha^{-1} using 75 cm row spacing at Rustenburg and 300 000 plants ha^{-1} using 45 cm row spacing Bethlehem are recommended as optima for protein content.

6.2 Recommendations

Future studies that examines the potential residual effects of these practices on soil after crop harvest is recommended so as to assess the potential contribution of these different cultivars to nitrogen balance on farmers' fields at the three localities. Economic analysis of the individual commercial soybean cultivars based on the grain yield obtained from each locality is also recommended so as to help farmers and the soybean industry to make an economically viable and wise choice in terms of the best agronomic practice per soybean cultivar, planting density and locality. Finally, validation of these preliminary data and accompanying recommendations through the repeat planting of this trial over two to three years is recommended for yield stability and consistency under variable climatic and soil conditions that prevail at the different trial sites.

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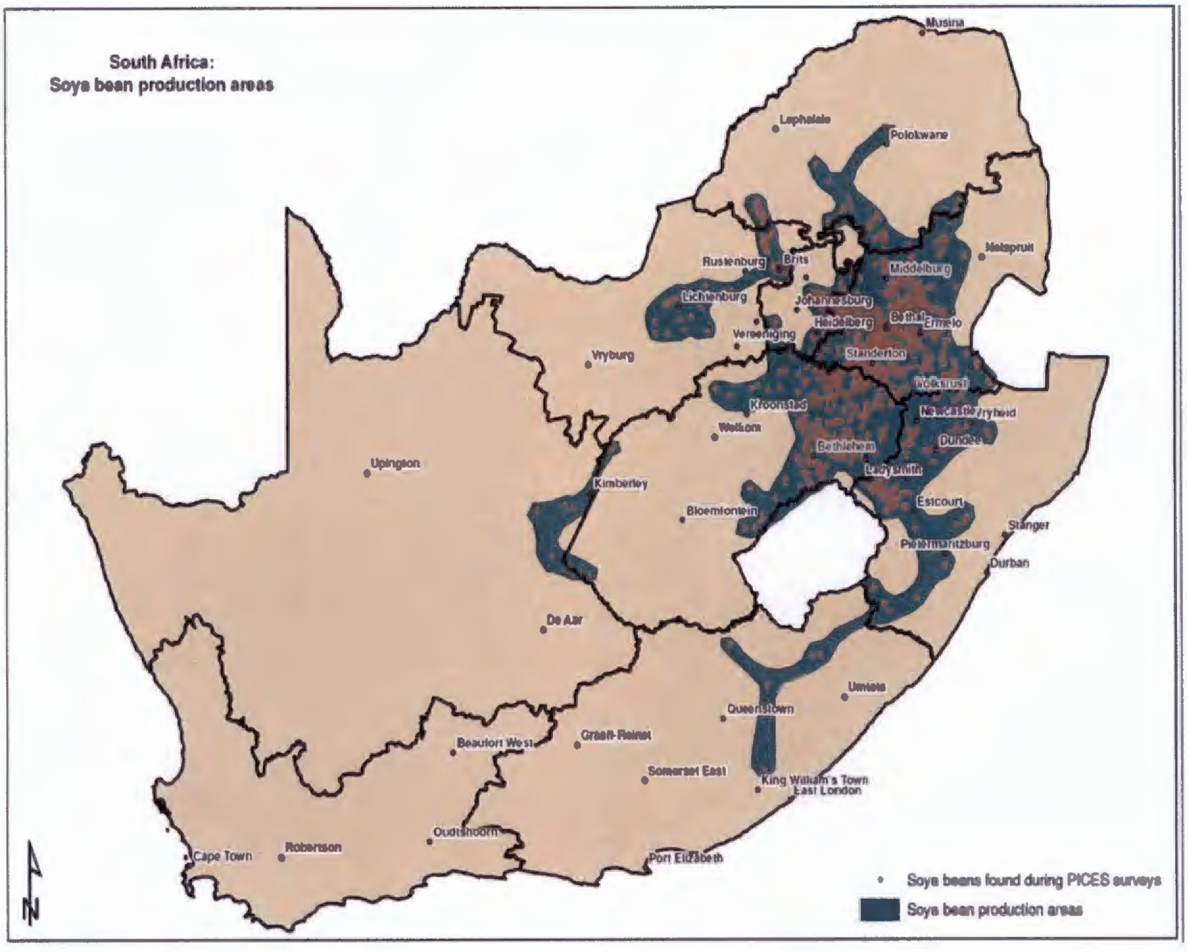
LIST OF APPENGICES



Appendix 1: Soybean production areas in South Africa

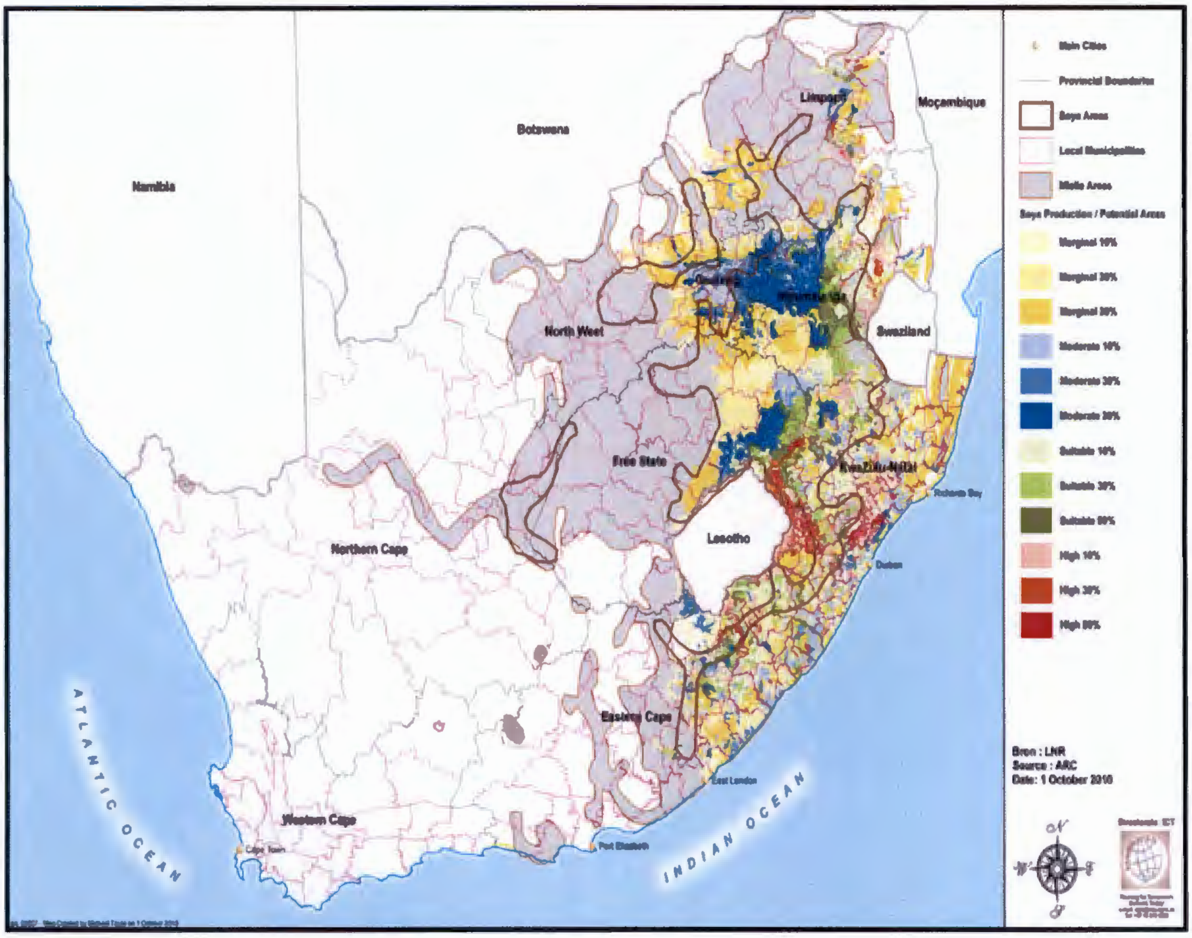
Appendix 2: The difference of soybean on field in different space between rows

200 000 p ha^{-1}

300 000 p ha^{-1}

450 000 p ha^{-1}

Appendix 3: The difference of soybean on field in different densities

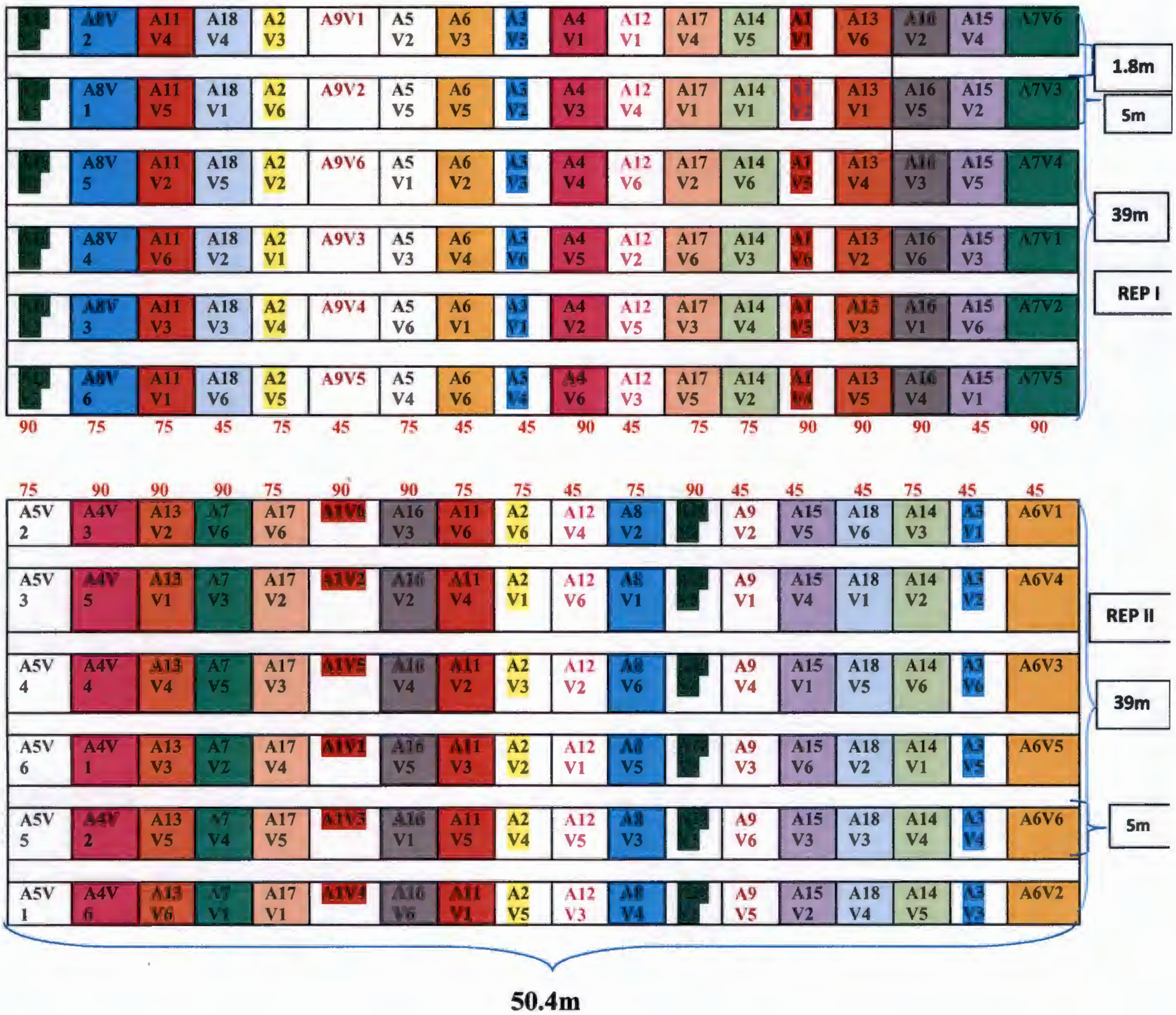


Appendix 4: Rainfall areas suitable for soybean production

Appendix 5: Treatments description for the trial (density × Space – row × cultivar)

DENSITY / SPACE and CULTIVARS	DENSITY / SPACE and CULTIVARS	DENSITY / SPACE and CULTIVARS
1-A1V1 : D1S1V1 90 Seeds/line	19-A4V1 : D2S1V1 113 Seeds/line	37-A7V1 : D3S1V1 135 Seeds/line
2-A1V2 : D1S1V2 90 Seeds/line	20-A4V2 : D2S1V2 113 Seeds/line	38-A7V2 : D3S1V2 135 Seeds/line
3-A1V3 : D1S1V3 90 Seeds/line	21-A4V3 : D2S1V3 113 Seeds/line	39-A7V3 : D3S1V3 135 Seeds/line
4-A1V4 : D1S1V4 90 Seeds/line	22-A4V4 : D2S1V4 113 Seeds/line	40-A7V4 : D3S1V4 135 Seeds/line
5-A1V5 : D1S1V5 90 Seeds/line	23-A4V5 : D2S1V5 113 Seeds/line	41-A7V5 : D3S1V5 135 Seeds/line
6-A1V6 : D1S1V6 90 Seeds/line	24-A4V6 : D2S1V6 113 Seeds/line	42-A7V6 : D3S1V6 135 Seeds/line
7-A2V1 : D1S2V1 75 Seeds/line	25-A5V1 : D2S2V1 94 Seeds/line	43-A8V1 : D3S2V1 113 Seeds/line
8-A2V2 : D1S2V2 75 Seeds/line	26-A5V2 : D2S2V2 94 Seeds/line	44-A8V2 : D3S2V2 113 Seeds/line
9-A2V3 : D1S2V3 75 Seeds/line	27-A5V3 : D2S2V3 94 Seeds/line	45-A8V3 : D3S2V3 113 Seeds/line
10-A2V4 : D1S2V4 75 Seeds/line	28-A5V4 : D2S2V4 94 Seeds/line	46-A8V4 : D3S2V4 113 Seeds/line
11-A2V5 : D1S2V5 75 Seeds/line	29-A5V5 : D2S2V5 94 Seeds/line	47-A8V5 : D3S2V5 113 Seeds/line
12-A2V6 : D1S2V6 75 Seeds/line	30-A5V6 : D2S2V6 94 Seeds/line	48-A8V6 : D3S2V6 113 Seeds/line
13-A3V1 : D1S3V1 45 Seeds/line	31-A6V1 : D2S3V1 57 Seeds/line	49-A9V1 : D3S3V1 68 Seeds/line
14-A3V2 : D1S3V2 45 Seeds/line	32-A6V2 : D2S3V2 57 Seeds/line	50-A9V2 : D3S3V2 68 Seeds/line
15-A3V3 : D1S3V3 45 Seeds/line	33-A6V3 : D2S3V3 57 Seeds/line	51-A9V3 : D3S3V3 68 Seeds/line
16-A3V4 : D1S3V4 45 Seeds/line	34-A6V4 : D2S3V4 57 Seeds/line	52-A9V4 : D3S3V4 68 Seeds/line
17-A3V5 : D1S3V5 45 Seeds/line	35-A6V5 : D2S3V5 57 Seeds/line	53-A9V5 : D3S3V5 68 Seeds/line
18-A3V6 : D1S3V6 45 Seeds/line	36-A6V6 : D2S3V6 57 Seeds/line	54-A9V6 : D3S3V6 68 Seeds/line
55-A10V1 : D4S1V1 158 Seeds/line	73-A13V1 : D5S1V1 180 Seeds/line	91-A16V1 : D6S1V1 203 Seeds/line
56-A10V2 : D4S1V2 158 Seeds/line	74-A13V2 : D5S1V2 180 Seeds/line	92-A16V2 : D6S1V2 203 Seeds/line
57-A10V3 : D4S1V3 158 Seeds/line	75-A13V3 : D5S1V3 180 Seeds/line	93-A16V3 : D6S1V3 203 Seeds/line
58-A10V4 : D4S1V4 158 Seeds/line	76-A13V4 : D5S1V4 180 Seeds/line	94-A16V4 : D6S1V4 203 Seeds/line
59-A10V5 : D4S1V5 158 Seeds/line	77-A13V5 : D5S1V5 180 Seeds/line	95-A16V5 : D6S1V5 203 Seeds/line
60-A10V6 : D4S1V6 158 Seeds/line	78-A13V6 : D5S1V6 180 Seeds/line	96-A16V6 : D6S1V6 203 Seeds/line
61-A11V1 : D4S2V1 132 Seeds/line	79-A14V1 : D5S2V1 150 Seeds/line	97-A17V1 : D6S2V1 169 Seeds/line
62-A11V2 : D4S2V2 132 Seeds/line	80-A14V2 : D5S2V2 150 Seeds/line	98-A17V2 : D6S2V2 169 Seeds/line
63-A11V3 : D4S2V3 132 Seeds/line	81-A14V3 : D5S2V3 150 Seeds/line	99-A17V3 : D6S2V3 169 Seeds/line
64-A11V4 : D4S2V4 132 Seeds/line	82-A14V4 : D5S2V4 150 Seeds/line	100-A17V4 : D6S2V4 169 Seeds/line
65-A11V5 : D4S2V5 132 Seeds/line	83-A14V5 : D5S2V5 150 Seeds/line	101-A17V5 : D6S2V5 169 Seeds/line
66-A11V6 : D4S2V6 132 Seeds/line	84-A14V6 : D5S2V6 150 Seeds/line	102-A17V6 : D6S2V6 169 Seeds/line
67-A12V1 : D4S3V1 79 Seeds/line	85-A15V1 : D5S3V1 90 Seeds/line	103-A18V1 : D6S3V1 102 Seeds/line
68-A12V2 : D4S3V2 79 Seeds/line	86-A15V2 : D5S3V2 90 Seeds/line	104-A18V2 : D6S3V2 102 Seeds/line
69-A12V3 : D4S3V3 79 Seeds/line	87-A15V3 : D5S3V3 90 Seeds/line	105-A18V3 : D6S3V3 102 Seeds/line
70-A12V4 : D4S3V4 79 Seeds/line	88-A15V4 : D5S3V4 90 Seeds/line	106-A18V4 : D6S3V4 102 Seeds/line
71-A12V5 : D4S3V5 79 Seeds/line	89-A15V5 : D5S3V5 90 Seeds/line	107-A18V5 : D6S3V5 102 Seeds/line
72-A12V6 : D4S3V6 79 Seeds/line	90-A15V6 : D5S3V6 90 Seeds/line	108-A18V6 : D6S3V6 102 Seeds/line
D1 - 200 000 pl/ha D4 - 350 000 pl/ha	S1 – 90 Cm between lines	V1 – LS 6240 R V4 – PAN 1500 R
D2 – 250 000 pl/ha D5 – 400 000 pl/ha	S2 – 75 Cm between lines	V2 - PAN 1454 R V5 – LS 6164 R
D3 – 300 000 pl/ha D6 – 450 000 pl/ha	S3 – 45 Cm between lines	V3 – PAN 1664 R V6 – PAN 1614 R

Appendix 6: Field Plan/layout



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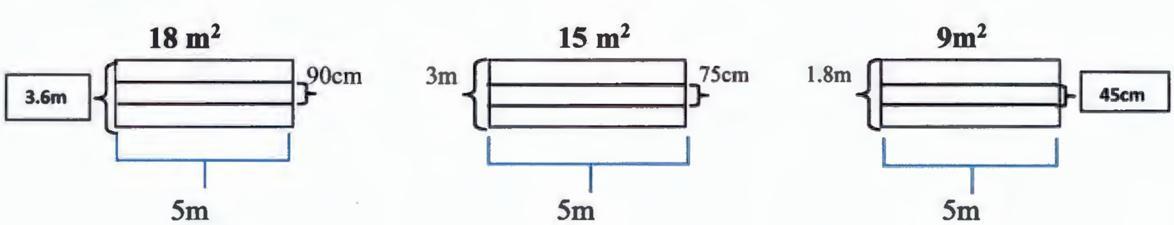

Appendix 7: Spectrometer-Near Infrared (NIR) - Ifratec 1241 Analyzer serial № 12410942 110-120 / 220-240 v part № 10008285.

Appendix 8: Anova for Percentage of Emergence, Height of Plant and Height of Pod

		Percentage of Emergence		Height of Plant		Height of Pod	
Source	DF	MS	P	MS	P	MS	P
Locality	2	25470.53	**<.0001**	442.6111	**<.0001**	137.5175	**<.0001**
Density	17	251.35375	**<.0001**	2.873221	**0.0002**	1.8834	**0.0195**
Locality*Density	34	383.40621	**<.0001**	1.203751	0.2111	1.062564	0.3807
Cult	5	7060.5973	**<.0001**	227.1045	**<.0001**	256.0661	**<.0001**
Locality*Cult	10	946.93962	**<.0001**	4.774405	**<.0001**	7.93675	**<.0001**
Density*Cult	85	221.87417	0.0804	1.365242	**0.0326**	1.204036	0.1354
Locality*Density*Cult	170	293.40792	1.7005	1.147931	0.1561	1.11229	0.2174
Error	270						
Total	647						

Appendix 9: Anova for 50% flowering, 50% physiological maturity and 50% harvest maturity

		50% flowering		50% physiological maturity		50% harvest maturity	
Source	DF	MS	P	MS	P	MS	P
Locality	2	35372.55	**<.0001**	6498.000	**<.0001**	11438.00	**<.0001**
Density	17	0.44599	0.0901	0.00	1.000	0.000	1.0000
Locality*Density	34	0.44599	0.1253	0.00	1.000	0.000	1.0000
Cult	5	12868.75	**<.0001**	6022.80	**<.0001**	13629.2	**<.0001**
Locality*Cult	10	129.8904	0.2436	1522.80	0.2754	3275.60	0.07541
Density*Cult	85	0.17932	0.8890	0.00	0.100	0.000	1.000
Locality*Density*Cult	170	0.17932	0.9471	0.00	0.100	0.000	1.000
Error	270						
Total	647						

Appendix 10: Anova for Number of plant lodged

		Number of plant lodged	
Source	DF	MS	P
Locality	2	1225.00	0.3245
Density	17	342.516	0.8421
Locality*Density	34	278.003	0.9220
Cult	5	79.5370	0.4761
Locality*Cult	10	9.53703	0.1030
Density*Cult	85	73.0042	0.0703
Locality*Density*Cult	170	31.1710	0.6004
Error	270		
Total	647		

Appendix 11: Anova for Number of plant, Weight of 100 seeds and Moisture of seed

		Number of Plant		Seed Mass		Seed Moisture	
Source	DF	MS	P	MS	P	MS	P
Locality	2	273.42	**<.0001**	658.5183	**<.0001**	469.9025	**<.0001**
Density	17	46.90	**<.0001**	1.48071	0.101	1.104224	0.3492
Locality*Density	34	2.13	**0.0003**	1.283225	0.1435	1.009158	0.4593
Cult	5	27.59	**<.0001**	360.2442	**<.0001**	4.388222	**<.0007**
Locality*Cult	10	1.50	0.1369	9.760637	**<.0001**	16.74607	**<.0001**
Density*Cult	85	1.27	0.0625	1.287099	0.0676	1.127812	0.2357
Locality*Density*Cult	170	1.15	0.1516	1.071612	0.3048	0.979081	0.5564
Error	270						
Total	647						

Appendix 12: Anova for Grain Yield, Protein content and Oil content

		Yield		Protein		Oil	
Source	DF	MS	P	MS	P	MS	P
Locality	2	94.612454	**<.0001**	686.10	**<.0001**	68.01455	**<.0001**
Density	17	26.21783	**<.0001**	1.098371	**0.0003**	0.3301679	**0.0003**
Locality*Density	34	3.3131176	**<.0001**	0.940827	**<.0001**	0.1362028	0.2699
Cult	5	0.9761561	0.4327	89.778867	**<.0001**	27.433164	**<.0001**
Locality*Cult	10	23.66863	**<.0001**	14.04633	**<.0001**	6.2810154	**<.0001**
Density*Cult	85	1.3357787	**0.0433**	0.561501	0.0608	0.1183139	0.4931
Locality*Density*Cult	170	1.1176726	0.2072	0.501876	0.0553	0.1356069	0.163
Error	270						
Total	647						

Appendix 13: Abstract

RESPONSE OF COMMERCIAL SOYBEAN TO VARIANCE IN PLANT DENSITY ON SELECTED QUALITY TRAITS AT DIFFERENT ECOTYPES IN SOUTH AFRICA

G F Braga[1] F R Kutu[2] A S de Beer[1]

[1]*ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520*

[2]*Department of Crop Science, North West University (Mafikeng Campus), Private Bag X2046, Mmabatho 2735, South Africa*

Email: bragagabriel74@gmail.com

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is cultivated in many countries of the tropics and subtropics. It is popular in Japan, Korea, China and Taiwan, while is global consumption is increasing very rapidly. Soybean is a rich source of vitamin A and a good source of carbohydrate, protein, oil and iron. Globally, soybean is probably the largest source of vegetable seed oil and protein as it contains about 40% crude protein and 20% oil. In South Africa farmers are more interested on obtaining the seed density that will concurrently improve seed yields and oil, thus lead to competitive market. To this end, farmers across the country are applying soybean seed density at individual discretion. This study was, therefore, initiated to evaluate the effect of plant density on the protein and oil of six soybean cultivars grown at three localities in South Africa.

MATERIALS AND METHODS

An agronomic field trial was conducted at Potchefstroom, Rustenburg and Bethlehem during 2013/14 summer planting season. Treatments consisted of six plant densities (200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plant/ha) and six round-up ready (R) soybean cultivars (LS 6240, PAN1454, PAN 1654, PAN 1500, LS 6164 and PAN 1614) at three rows spacing (45, 75 and 90 cm). Treatments were laid out in a randomised complete block design in split-split plot arrangement. All data collected were tested for comparable magnitude before a weighted combined analyses of variance was performed using SAS. Shapiro-Wilk's test was performed on the standardised residuals to test for deviation from the normality. Pairwise comparison was also performed on the least square means of significant effects using the Fishers LSD-test at 5% probability level.

RESULTS

The protein of soybean at Rustenburg was significantly affected by density, cultivar, locality .x density and locality x cultivar interaction effects having higher protein (44.1%) than either Bethlehem (41.1%) or Potchefstroom (40.9%). Soybean planted at 400 000 plants ha^{-1} using 75 cm row spacing gave the highest protein content of 44.5%. The cultivar LS 6164R had best protein content of 45.3% at Rustenburg. The oil content in soybean at Potchefstroom was significantly affected by density, cultivar and locality x cultivar interaction effects with higher oil content of 21.0% than either Rustenburg (20.2%) or Bethlehem (20.0%). The highest oil content of 21.9% was recorded at density of 350 000 plant ha^{-1} using 75 cm spacing row with cultivar LS 6240R at Potchefstroom, while PAN 1664R had lowest oil content of 19.3% at Bethlehem.

CONCLUSION

Seed protein content was high at Rustenburg (45.3%) using plant density 400 000 plants ha^{-1}, 75 cm row spacing and LS 6164R cultivar. The plant density of 350 000 plants ha^{-1} using 75 cm row spacing gave the highest oil content of 21.9% at Potchefstroom with cultivar LS 6240R.

Keywords: Oil, plant density, protein, row spacing, soybean cultivars

Appendix 14: Abstract

EFFECT OF PLANT DENSITY ON THE PERFORMANCE OF SIX SOYBEAN CULTIVARS GROWN AT THREE LOCALITIES IN SOUTH AFRICA

G F Braga[1] F R Kutu[2] A S de Beer[1]

[1]ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520

[2]Department of Crop Science, North West University (Mafikeng Campus), Private Bag X2046, Mmabatho 2735, South Africa

Email: bragagagabriel74@gmail.com

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is cultivated in many countries of the tropics and subtropics. It is popular in Japan, Korea, China and Taiwan, while is global consumption is increasing very rapidly. Soybean is a rich source of vitamin A and a good source of carbohydrate, protein, oil and iron. Globally, soybean is probably the largest source of vegetable seed oil and protein as it contains about 40% crude protein and 20% oil. In South Africa, farmers are more interested on obtaining the seed density that will concurrently improve seed yields and oil, thus leading them to competitive markets. To this end, farmers across the country are applying soybean seed density at individual discretion. This study was, therefore, initiated to evaluate the effect of plant density on the productivity of six soybean cultivars grown at three localities in South Africa.

MATERIALS AND METHODS

An agronomic field trial was conducted at Potchefstroom, Rustenburg and Bethlehem during 2013/14 summer planting season. Treatments consisted of six plant densities (200 000, 250 000, 300 000, 350 000, 400 000 and 450 000 plant/ha) and six round-up ready (R) soybean cultivars (LS 6240, PAN1454, PAN 1654, PAN 1500, LS 6164 and PAN 1614) at three rows spacing (45, 75 and 90 cm). Treatments were laid out in a randomised complete block design in split-split plot arrangement. All data collected were tested for comparable magnitude before a weighted combined analyses of variance was performed using SAS. Shapiro-Wilk's test was performed on the standardised residuals to test for deviation from the normality. Pairwise comparison was also performed on the least square means of significant effects using the Fishers LSD-test at 5% probability level.

RESULTS

The interaction effects of locality x density, locality x cultivar and density x cultivar were significant for soybean grain yield. Potchefstroom had the highest mean grain yield of 4390 kg ha^{-1} across all treatments while Rustenburg had the lower yield of 3410 kg ha^{-1}. Soybean planted at 400 000 plants ha^{-1} and 45 cm row spacing gave the highest yield of 5176 kg ha^{-1}, while lowest yield of 3085 kg ha^{-1} was obtained at 200 000 plant ha^{-1} and 90 cm row spacing. On the interaction of locality x density, significantly higher yield of 6004 kg ha^{-1} was obtained at Potchefstroom with 400 000 plants ha^{-1} and 45 cm row spacing, while low yield (2407 kg ha^{-1}) was observed at Rustenburg with 350 000 plant ha^{-1} and 90 cm row spacing. Interaction of locality x cultivar showed that PAN 1500R planted at Potchefstroom and recorded yield (4749 kg ha^{-1}) significantly higher than LS 6240R with 2587 kg ha^{-1} at Rustenburg. The interaction of density x cultivar showed that PAN 1500R planted at 400 000 plants ha^{-1} and 45 cm gave best yield of (5820kg ha^{-1}) significantly higher than PAN1454R planted at 350 000 plants ha^{-1} and 90cm (2510kg ha^{-1}).

CONCLUSION

Across the sites, soybean grain yield was significantly affected by plant density. There were locality x density, locality x cultivar and density x cultivar interaction effects on soybean seed yield. The plant density of 400 000 plants ha^{-1} at row spacing of 45 cm resulted in highest soybean yield for all the cultivars.

Key words: Plant density, row spacing, seed yield, soybean cultivars