AGRONOMIC STUDIES ON EDAMAME (VEGETABLE SOYBEAN) IN KWAZULU-NATAL

by

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Submitted in fulfilment of the academic requirements for the degree of

Master of Science in Agriculture

Discipline of Agronomy

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

November, 2015

PREFACE

The research contained in this thesis was completed by the candidate while registered in the Discipline of Agronomy, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the KwaZulu-Natal Department of Agriculture and Rural Development.

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

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Signed:

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DECLARATION

I, ARTHUR JAMES ARATHOON, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons‟ data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

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ABSTRACT

Vegetable soybean (*Glycine max* (L.) Merrill), also known as edamame, originated in China, but is now grown in many parts of the world, where its high protein content and beneficial health benefits are being recognized as a valuable food source for human consumption. The green pods are picked at the R6 growth stage when the beans have filled 80 - 90% of the pod. The pods are shelled and the beans are eaten, usually as a snack or included in salads, stir-fries and soups.

Vegetable soybean is poorly known in South Africa. However, as in South East Asia, the crop could be economically viable for small-scale and commercial farmer production. As minimal previous research had been conducted on vegetable soybean in South Africa, the objectives of this study were to identify the best performing cultivars for KwaZulu-Natal, determine the most suitable seeding rate, determine the crop"s phosphorus and potassium requirements, to evaluate the effect of seed coatings with fungicides and *Bradyrhizobium japonicum* Kirchner inoculants on plant population, nodulation and yield, and to estimate the costs and profitability of producing and marketing the crop. The research trials were conducted primarily on the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), but also on the Dundee Research Station (latitude 28°13'S; longitude 30°31'E; altitude 1219 m), of the KwaZulu-Natal Department of Agriculture and Rural Development, South Africa.

Two medium-season cultivars (AGS 353 and AGS 354) and two long-season cultivars (AGS 352 and Lightning) were evaluated at the Cedara Research Station at seeding rates of 200 000, 300 000, 400 000 and 500 000 seeds ha^{-1} in four plantings from 2005 to 2008. No significant differences in mean seed yield were measured between the seeding rates. However, a significant interaction was measured for seed yield between the cultivars and seasons. AGS 354 produced significantly greater yields in the higher production seasons, 2007/08 (1) and 2005/06, and produced a significantly higher mean yield than AGS 352 and Lightning. Lightning produced the highest yields in the low production seasons, 2006/07 and 2007/08 (2), and the lowest yields in the high production seasons. AGS 352 produced the lowest yields in the lower production seasons. Similarly, at seeding rates from 50 000 to 250 000 seeds ha^{-1}, no significant differences in mean seed yield were measured between the seeding rates for AGS 353, AGS 354, Lightning and the short-season cultivar, AGS 292, when evaluated in the 2012/13 and 2013/14 seasons. However, AGS 292, which was only evaluated in the 2013/14 season, yielded significantly better from 150 000 to 250 000 seeds ha^{-1} than from 50 to 100 000 seed ha^{-1}. Due to the short plant height of AGS 292, the plants

did not canopy in the 0.75 m wide rows and weeds competed with the crop, resulting in a low mean yield of 1.9 t ha^{-1} compared to the mean yield of 3.5 t ha^{-1} for the other three cultivars. Although significantly more branches $plant^{-1}$ were produced by AGS 292 at the lower seeding rates, no significant differences in the number of pods $plant^{-1}$ were measured. In both experiments, plant population was not significantly correlated to yield. Overall, as seeding rate decreased, plant height and bottom pod height decreased significantly, whilst significantly more branches containing more pods were produced per plant, but significantly fewer pods per hectare were produced. Seed size decreased significantly as the seeding rate increased from 200 000 to 500 00 seeds ha^{-1}, but not at seeding rates from 50 000 to 250 000 seeds ha^{-1}. At seeding rates from 200 000 to 500 000 seeds ha^{-1}, no significant differences in the percentage export marketable pods were measured between the seeding rates. However, at seeding rates from 50 000 to 250 000 seeds ha^{-1}, significantly higher percentages of export marketable pods were measured from 50 000 to 150 000 seeds ha^{-1} than from 200 000 to 250 000 seeds ha^{-1}.

Twenty cultivars were evaluated at the Cedara Research Station at a seeding rate of 266 667 seeds ha^{-1} in four trials from 2010 to 2013. The mean number of days from planting to green pod harvest ranged from 81 for AGS 329 to 125 for AGS 352 and Lightning. Significant interactions were measured among the cultivars and seasons for all the agronomic characteristics measured due to variations in plant population, which resulted from poor germination of some cultivars in certain seasons and hail damage that occurred in the 2012/13 season. The shorter-season cultivars were more affected by the hail than the longer-season cultivars, due to less recovery time. A significant positive correlation was measured between plant population and the green pod and bean yields. AGS 440 had the lowest mean plant population of 90 000 plant ha^{-1}, whilst AGS 457 had the highest mean plant population of 233 600 plants ha^{-1}. The longer-season cultivars had significantly taller plants with significantly higher bottom pod heights, and more branches and pods per plant, and consequently produced significantly higher mean green pod yields than the shorter-season cultivars. Mean number of pods $plant^{-1}$ ranged from 14.8 to 36.5 for AGS 425 and AGS 352, respectively. AGS 440 (47.7 g) and Lightning (26.4 g) had the highest and lowest 100-seed masses, respectively. However, mean green pod yield ranged from 7.4 t ha^{-1} for AGS 440 to 12.1 t ha^{-1} for the long-season cultivar, Lightning. Green bean yield ranged from 3.6 t ha^{-1} for the short-season cultivar AGS 292 to 6.7 t ha^{-1} for Lightning. Mean crude protein content ranged from 41.1% for AGS 418 to 44.5% for AGS 335, whilst fat content ranged from 15.4% for AGS 437 to 19.2% for AGS 352. Significant positive correlations were measured between percentage fat and percentage crude protein, pod yield and bean yield, but no significant correlation was measured between percentage crude protein and the pod and bean yields.

The influences of phosphorus (P) application rates of 0, 30 and 60 kg ha^{-1} and potassium (K) application rates of 0, 40, 80 120 and 160 kg ha^{-1} were determined on the production of AGS 353 and Lightning grown on a Hutton soil at the Cedara Research Station in the 2012/13 and 2013/14 seasons. Soil tests revealed means of 8.2 mg P L^{-1} and 57.9 mg K L^{-1} before the fertilizer applications were made. Plant population was significantly higher in the 2012/13 season for both cultivars, but had no significant correlation with mean pod and bean dry matter (DM) yields. Lightning produced significantly taller plants, more pods $plant^{-1}$, a higher percentage of export marketable pods (≥ 2 seeds pod^{-1}) and total plant, pod and bean DM yields than AGS 353. P application rate had no significant effect on plant and bottom pod height. However, plant height increased significantly from 0 to 120 kg K ha^{-1}, whilst bottom pod height decreased significantly, due to significantly higher percentages of seedless pods as K application rate decreased. The number of pods $plant^{-1}$ was significantly higher at 60 kg P ha^{-1} than at the lower P applications, but K application rate had no significant effect on the number of pods $plant^{-1}$. Pod and bean DM yields increased significantly from 0 to 60 kg P ha^{-1} and from 0 to 40 kg K ha^{-1}. Significant interactions were measured for pod and bean DM yields between the seasons, cultivars and K applications. In the 2012/13 season, Lightning produced significantly lower pod and bean DM yields at 0 kg K ha^{-1}, but no significant differences were measured in the 2013/14 season. However, in the 2013/14 season, AGS 353 produced a significantly lower pod DM yield at 0 kg K ha^{-1} than at 40 and 120 kg K ha^{-1}, whilst a significantly lower bean DM yield was produced at 0 kg K ha^{-1} than from 40 to 120 kg K ha^{-1}. In the 2012/13 season no significant differences in pod DM yield were measured for AGS 353 between the K application rates. However, at 0 kg K ha^{-1}, bean DM yield was significantly lower than at 120 kg K ha^{-1}. The highest mean bean DM yield was produced at the combination of 60 kg P ha^{-1} and 120 kg K ha^{-1}.

At harvest in 2011 some Phomopsis infected pods were observed among the twenty one cultivars planted in a cultivar evaluation trial. The „clean" seeds of those cultivars were planted in an unreplicated demonstration trial at the Cedara Research Station on 2 December 2011. Each cultivar was planted in a plot with eight rows of 8 m length and spaced 0.75 m apart. The plots were split for (a) the application of the fungicide, thiram, to the seed at planting, and (b) no application of thiram. Thiram was applied at a rate of 20 g 16 L^{-1} water with a knapsack sprayer delivering 250 L ha^{-1} to the seed after it had been manually placed in the row at a seeding rate of 266 667 seeds ha^{-1}. Percentage emergence, which varied significantly between the cultivars and ranged from 2.8% to 98.1%, was significantly negatively correlated to 100-seed mass at planting. A significantly higher emergence percentage was obtained when thiram was applied (52.0%) compared to the no thiram application (42.2%). Plant height, bottom pod height and yield were significantly higher when thiram was applied, but 100-seed size was significantly lower. In an experiment conducted in the 2012/13 and 2013/14 seasons, the fungicides, thiram and captan, and the bio-fungicide, Eco-T®, were applied as coatings to the seed of four edamame cultivars, AGS 352, AGS 353, AGS 354 and Lightning, and compared with a Control treatment (no fungicide). The application of thiram at 150 g 100 kg^{-1} of seed and captan at 115 g 100 kg^{-1} of seed resulted in significantly higher plant populations than Eco-T® applied at 1 g kg^{-1} of seed and the Control treatment. However, no significant differences were measured between the fungicide treatments for nodule number $plant^{-1}$, percentage active nodules, plant height, bottom pod height, 100-seed mass and seed yield. AGS 353 and Lightning produced significantly lower mean yields than AGS 352 and AGS 354.

Three commercially available *Bradyrhizobium japonicum* Kirchner inoculants, Soycap, Eco-Rhizsoy® and Hi-stick®, were evaluated against a Control treatment (no inoculation) for the nodulation and yield of the vegetable soybean cultivars, AGS 352, AGS 353, AGS 354 and Lightning at the Cedara Research Station in the 2012/13 and 2013/14 seasons and in the 2013/14 season at the Dundee Research Station. At the Cedara Research Station a significantly higher number of nodules $plant^{-1}$ was measured and, due to higher rainfall received during pod-fill, a significantly greater seed yield was measured in the 2013/14 season than in the 2012/13 season. No significant differences were measured among the inoculant treatments for plant population, plant height, bottom pod height, 100-seed mass, percentage leaf N at flowering, nodule number $plant^{-1}$, nodule mass $plant^{-1}$ and percentage active nodules. The application of Soycap and Eco-Rhizsoy® resulted in significantly higher yields than the Control treatment, whilst at the Dundee Research Station no significant differences in yield were measured among the inoculant treatments. In all three trials yield was significantly positively correlated to percentage leaf N at flowering, but not to nodule number $plant^{-1}$ and nodule mass $plant^{-1}$. At the Cedara Research Station, Lightning produced a significantly lower mean yield when not inoculated with *Rhizobia* and, overall, a significantly lower mean yield than the other cultivars. AGS 352 produced a significantly higher mean yield than AGS 353. However, at Dundee, Lightning produced a significantly higher mean yield than the other cultivars.

A financial analysis was undertaken to determine the costs and profitability of vegetable soybean when produced under dryland and irrigated conditions and marketed as (a) fresh ungraded green pods in 10 kg vegetable pockets, (b) marketable fresh green pods (≥ 2

beans pod^{-1}) sold in 10 kg vegetable pockets and the 1-seeded pods shelled and sold as fresh green beans in plastic punnets, and (c) the whole crop sold as shelled fresh green beans in plastic punnets. It was considered that land preparation, planting and spraying operations were done mechanically, whilst labour was used for hand-harvesting, grading and packing at R120.32 per nine hour day. A shelling machine is used to shell the pods. Fresh green pod yields of 7 and 10 t ha^{-1} are used for dryland and irrigation, respectively. Five percent of the crop is rejected due to damages and malformation. The percentage marketable green pods is 70% and 80% for dryland and irrigation, respectively. A price of R7.00 kg^{-1} is used for marketable pods, but adjusted according to the percentage marketable pods when all the green pods are sold. The fresh green beans are sold at R20.00 kg^{-1}. Marketing agents are used to sell the crop, which is delivered to the market by a transport contractor. The higher yields produced with irrigation result in greater gross margins ha^{-1} above total allocatable variable costs (TAVC) and returns on investment (ROI) than the yields produced under dryland conditions. The lowest gross margins ha^{-1} above TAVC of R17 117.12 and R32 337.98 are obtained with dryland and irrigation, respectively, when all the ungraded green pods are sold in 10 kg vegetable pockets. The highest gross margins ha^{-1} above TAVC of R36 921.67 and R54 544.23 are obtained with dryland and irrigation, respectively, when the whole crop is marketed as green beans in plastic punnets. With the cost and prices used, edamame production can be economically viable in KwaZulu-Natal.

ACKNOWLEDGEMENTS

I gratefully acknowledge:

Professor M.D. Laing, my supervisor, for willingly accepting me as a student, sharing his vast knowledge, giving generous advice, displaying enthusiasm for the topic and providing encouragement. I am also extremely grateful to him for reviewing and editing this thesis.

The KwaZulu-Natal Department of Agriculture and Rural Development, my employer, for granting me the opportunity to conduct the research work on vegetable soybean and to include the results in this thesis.

My many colleagues, who have given so much support and encouragement, but in particular I thank the following:

- The staff of the Agronomy Section based at the Cedara and Dundee Research Stations, who have assisted enormously with the planting, management and harvesting of the research trials and with the data collection.
- Mrs. C. Stevens for the many hours she spent willingly assisting with the statistical analyses.
- Dr. J. de Villiers, I. Macdonald, R. Stuurman and M. Hoosein for their assistance in resolving technical issues.
- Dr. S. Bezuidenhout, Dr. A. Manson and Ms. A. Nunkumar for their advice, support, editing and continuous encouragement.
- Ms. G. Archer for assistance with the financial budgets.
- Staff of the Soil, Plant and Feed Laboratories at Cedara for the analyses conducted.
- Farm Services for preparing the lands for planting.

The AVRDC – The World Vegetable Center for allowing me to conduct research trials with its vegetable soybean cultivars.

The Edamame Development Program, PO Box 76355, Marbleray, 4037 (info@edamame.co.za and www.edamame.co.za) and the Agricultural Research Council – Grain Crops Institute, Potchefstroom, for the initial supply of vegetable soybean seed.

Soygro (Pty) Ltd., Plant Health Products (Pty) Ltd. and BASF South Africa (Pty) Ltd. for the supply of *Bradyrhizobium japonicum* inoculants and bio-fungicides.

My family for all their support and encouragement.

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INTRODUCTION

The research presented in this thesis was undertaken in the Discipline of Agronomy, University of KwaZulu-Natal, Pietermaritzburg, South Africa, under the supervision of Prof. M.D. Laing.

Soybean (*Glycine max* (L.) Merrill) originated in South East Asia and was first planted by Chinese farmers around 1100 BC (Anonymous, last accessed 06/11/2015). As its value as a high-protein (38% dry weight) human and animal food source and its use for industrial purposes were recognised, the crop became grown in many parts of the world. Global production in the 2013/14 season was 276 million tons (Geohive, last accessed 26/08/2015). The first mention of soybean being grown in South Africa appears in the "Cedara Memoirs of 1903" (Sawer, 1911). Almost one million tons of grain soybean are produced in South Africa annually (GrainSA, last accessed 19/11/2015). However, vegetable soybean, which is also known as edamame and is grown for human consumption as a green bean, occupies less than 2% of the global soybean production (Keatinge *et al*., 2011). The earliest reference to vegetable soybean was found in Chinese writings dating to the second century BC (Swathi, 2009). In South Africa there is no known commercial production of vegetable soybean, although occasionally it is found in some leading food stores. However, the Ethekwini (Durban) Municipality has an initiative through the Edamame Development Program to encourage rural households to produce edamame.

Vegetable soybean has larger seeds (Zhang *et al*., 2009) that are more tender, sweeter and have a "nuttier" flavour than grain soybean (Zhang and Kyei-Boahen, 2007). The pods are picked when they are green and when the beans occupy about 80 – 90% of the pod. The pods are boiled for a few minutes to soften them and then the beans are squeezed out and eaten, usually as a snack or included in salads, stir fries and stews (Mentreddy *et al*., 2002). Edamame is mainly eaten in China, Japan, Korea and Taiwan, but due to its recognition as a highly nutritional and health-benefitting crop and due to its tastiness, edamame is now grown in many other parts of the world (Duppong and Hatterman-Valenti, 2005; Sciarappa *et al*., 2007; Sharma, 2013).

As vegetable soybean is a new crop in South Africa, research work is necessary to determine the crop"s response to the prevailing environmental conditions, which can vary considerably from one area to another. Within KwaZulu-Natal, the climatic conditions range from temperate to tropical. In 2001 the KwaZulu-Natal Department of Agriculture and Rural Development received from the Agricultural Research Council – Grain Crops Institute in

Potchefstroom, South Africa, seed of three cultivars, which had been bred by the AVRDC – The World Vegetable Center. The cultivars demonstrated good adaptability to the climatic conditions experienced at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), which is situated in the Mistbelt of the KwaZulu-Natal Midlands, where a mean annual rainfall of 880 mm is received (Camp, 1990).

In 2005 research experiments with these three cultivars and one of unknown origin were initiated at Cedara. As recommended seeding rates for vegetable soybean varied considerably, these cultivars were evaluated at seeding rates from 200 000 to 500 000 seed ha^{-1}. Soybean growth is known to adjust to plant populations and spatial distributions in order to maximise production (Lee *et al.*, 2008; Suhre, 2012). No significant differences in yield were measured between the seeding rates. As a result, cultivars with varying growing-season lengths were then evaluated at seeding rates from 50 000 to 250 000 seeds ha^{-1}. For quality purposes, vegetable soybean is required to produce large seeds (≥ 30 g per 100 mature seeds to meet the export market requirements) and have two or more beans per pod (Mentreddy *et al*., 2002). The objectives of the experiment were to determine if these quality requirements were met without negatively affecting the yield, and to determine an optimal seeding rate for each maturity group.

As with other crops, identifying the most suitable cultivars for growing in the various production areas is essential if production and profitability are to be maximized. Cultivar evaluations are therefore an important part of a research program and are usually on-going, because new cultivars are being bred on a continuous basis. Cultivars, which were bred by the AVRDC – The World Vegetable Center in Taiwan and imported by the Edamame Development Programme, were evaluated at the Cedara Research Station. Apart from determining the adaptability and yield of the cultivars, other agronomic characteristics, such as growing-season length, plant height and seed mass, were also determined. Due to a shortage of staff, cultivar evaluations were not undertaken at other research stations in KwaZulu-Natal.

Soybean plants are known to respond well to applications of fertilizer and when the soil fertility is high (Liebenberg, 2012). Although intensive research work has been conducted on the fertility requirements of grain soybean in KwaZulu-Natal, it was felt necessary to determine whether vegetable soybean requires the same levels of phosphorus (P) and potassium (K) to yield optimally. Mahamood *et al*. (2009) and Sharma *et al*. (2011) reported that certain grain soybean cultivars responded differently to inadequate soil P levels. An experiment was therefore conducted to determine the yield response of two vegetable soybean cultivars to various applications of P and K. The site selected had low soil K levels before the experiment was conducted. Rural small-scale farmers may wish to grow the crop in South Africa, but as they are often resource-poor and usually have soils low in P and K nutrients, the trial may indicate what minimum levels of P and K will be required to produce an economically viable crop, whilst commercial farmers may want to maximize production and economic returns at higher applications of P and K.

Poor emergence and plant stands of vegetable soybean have been reported by researchers (Duppong and Hatterman-Valenti, 2005; Sanchez *et al*., 2005; Hamilton, 2007). This problem, however, was not confined to any one cultivar or season. It was noted in the initial seeding rate trials conducted at the Cedara Research Station that the plant populations were considerably lower than expected. Many factors can affect germination and emergence. Soil-borne pathogens can reduce emergence, whilst very cold and wet or hot and dry conditions will have a similar effect (Liebenberg, 2012). Seed size, quality and vigour may also affect emergence (Khalil *et al*., 2001; Khan *et al*., 2011). Vegetable soybean seeds are considerably larger than grain soybean seeds and, being more tender, may deteriorate more quickly or be attacked by soil-borne pathogens more easily. Humid conditions are regularly experienced at Cedara and therefore pod and seed infections of *Phomopsis longicolla* Hobbs can occur, which will result in poor germination (Li and Chen, 2013). An experiment was therefore conducted to evaluate the effect of applying two fungicides, thiram and captan, and one bio-fungicide, Eco-T®, as seed coatings at planting against a Control treatment on the plant stand. It has been reported that thiram and captan may reduce nodulation (Campo *et al*., 2009; Liebenberg, 2012) and therefore the number of nodules per plant and the yield were also measured for four cultivars. Isolates of *Trichoderma* species are being used for the suppression of various seed- and soil-borne diseases (Vinale *et al*., 2008). Eco-T® has *T. harzianum* as its active ingredient.

Variations in soybean nodule number, nodule mass and seed yield have been reported with various strains of *Bradyrhizobium japonicum* Kirchner (Zarrin *et al.*, 2007; Solomon *et al.*, 2012). Therefore, it was considered important to evaluate three commercially available *B. japonicum* inoculants, Soycap, Eco-Rhizsoy® and Hi-Stick®, against a Control treatment for their effect on the nodulation and yield of four vegetable soybean cultivars. South African soils do not have indigenous populations of the required *Rhizobia* to ensure that successful nodulation occurs. Therefore, the seeds have to be inoculated at planting, otherwise expensive applications of nitrogen will be required for the crop to yield optimally. Two sites on the Cedara Research Station were used for this trial and soybean had not been grown on them for at least ten years. A trial was also planted on a sandy Avalon soil on the Dundee

Research Station (latitude 28°13'S; longitude 30°31'E; altitude 1219 m), but the site had been planted to soybean four years prior to the experiment being planted.

When introducing a new crop, it is essential to determine whether the crop will be economically viable. As no commercial production exists in South Africa, determination of the profitability of edamame in South Africa is based on estimations. The planting and management of vegetable soybean is similar to grain soybean and therefore estimated production costs can be based on the costs incurred with grain soybean. Harvesting can be done mechanically with a harvester used for green beans (*Phaseolus vulgaris* L.) and will be more economical than using labour (Born, 2006). However, the harvest efficiency can vary from 54% to 85% depending on plant spacing and height (Zandonadi *et al*., 2009). There is a high level of unemployment in South Africa and therefore using labour to harvest, grade and pack the crop, as happens in South Africa with green bean production, will create job opportunities and assist in alleviating poverty. Shockley *et al*. (2011) calculated that greater net returns could be achieved with edamame than with grain soybean, but cautioned that there could be greater risk involved with edamame production and greater farming skills will be required due to very tight harvesting windows and the need to supply the market for as long a period as possible. The crop is harvested at the R6 growth stage when the sugars and amino acids required for good taste are at their peak (Duppong and Hatterman-Valenti, 2005; Zhang *et al*., 2007). For quality purposes, the pods should be dark green and contain ≥ 2 large beans pod^{-1} when marketed as green pods (Born, 2006; James, 2007). The 1-seeded pods can be mechanically shelled and the green beans sold in plastic punnets. Alternatively, the whole crop can be shelled and marketed in plastic punnets, for which higher prices will be obtained. In Japan the whole plant is sometimes sold, because the freshness of the pods is maintained for longer. Ultimately, the marketing methods will depend on the purchasers" requirements and the prices obtained will determine the profitability of the crop. A financial analysis of edamame production in KwaZulu-Natal has therefore been included in this thesis.

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CHAPTER ONE

LITERATURE REVIEW

1.1 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill) is the same species as grain or field soybean, but cultivars have been bred specifically for harvesting at an immature stage for direct consumption by humans (Rao *et al*., 2002). The earliest reference to vegetable soybean was found in Chinese writings dating to the second century BC (Swathi, 2009). The crop is regularly eaten in China, where it is called mao dou ("hairy bean"), in Japan, where it is known as edamame ("branched bean" or "beans on branches"), in Korea and in Taiwan (Miles *et al*., 2000; James, 2007; Zhang *et al*., 2007). Due to their tastiness and the known health benefits of soybean isoflavones (Duppong and Hatterman-Valenti, 2005; Sciarappa *et al*., 2007), vegetable soybean is now planted in many other parts of the world, but the production is less than 2% of world soybean production (Keatinge *et al*., 2011), which was 276.4 million tons in the 2013/14 season (Geohive, last accessed 26/08/2015). In South Africa 784 500 tons of grain soybean were produced in the 2013/14 season, of which 82 000 tons was produced in KwaZulu-Natal from 35 000 hectares (Dredge, 2014). However, no known commercial production of edamame exists in South Africa to date.

Vegetable soybean is produced in a similar manner to grain soybean, but is harvested when the pods are still bright green and the beans have filled 80% to 90% of the pod and are almost touching each other. This occurs at the reproductive growth stage R6, when the sugars and amino acids required for good taste are at their peak (Duppong and Hatterman-Valenti, 2005; Hamilton, 2007; Zhang *et al.*, 2007) and the moisture content of the beans is around 70% (Feibert *et al.*, 2001).

1.2 QUALITY REQUIREMENTS AND NUTRITIONAL PROPERTIES

Edamame, being a speciality crop, requires good management to produce a high-quality, directly consumed product. The key determinants of quality are large seed size (seed dry weight > 25 g 100-seeds^{-1}, but for the export market ≥ 30 g 100-seeds^{-1}), high sugar content, bright green colour with good flavour, texture and nutritional value. The pods should be dark green, have a light (white, grey or light brown) pubescence, contain at least two beans and be free of defects (Nelson *et al*., 2002; Born, 2006; James, 2007). The pods should be ≥ 5.0 cm in length and ≥ 1.4 cm in width (Mentreddy *et al*., 2002; Born, 2006).

The beans have a combination of low oil (18%) and high protein (38% dry weight) contents (Mentreddy *et al.*, 2002; Sanchez *et al.*, 2005), which are marginally higher than those of grain soybean, but the yields are considerably lower (Swathi, 2009; Zhang *et al*., 2009). The beans are an excellent substitute for animal-based protein that avoids saturated fats and cholesterol (Sciarappa *et al.*, 2007). They are a good source of dietary fibre, vitamin C (ascorbic acid), vitamin E (tocopherol), calcium and phytoestrogens. The health benefits of isoflavones include decreasing low-density lipoprotein and cholesterol levels and reducing the risk of cardiovascular diseases, cancer, osteoporosis and the incidence of menopausal symptoms such as hot flashes and night sweats (Duppong and Hatterman-Valenti, 2005; Sciarappa *et al*., 2007). Edamame contains a lower percentage of gas-producing starches than grain soybean (Born, 2006; Zhang and Kyei-Boahen, 2007), is more digestible and has lower levels of trypsin-inhibitor (Miles and Zenz, 1996).

FIGURE 1.1 Edamame growing on the Cedara Research Station, KwaZulu-Natal, South Africa

1.3 GROWING REQUIREMENTS

The required growing conditions for vegetable soybean are similar to those for grain soybean, which can be grown in areas ranging from temperate to tropical conditions. In KwaZulu-Natal, South Africa, temperate to sub-tropical conditions are experienced and therefore vegetable soybean can be grown in most areas where grain soybean (Figure 1.2), maize and sugarcane can be grown (Birch, 2002). Soybean requires deep (≥ 1m), well-drained loamy soils with good water retention and fertility with a pH of 6.0 to 7.5. Soil acid saturation should not be above 15% to 20% (Liebenberg, 2012; Lamptey *et al*., 2014). Apart from commercial production, edamame is highly suited to smallholder agriculture and home gardens, producing among the highest yields of crop protein per unit area. The crop can therefore contribute to alleviating malnutrition and hunger in resource-poor rural communities (Keatinge *et al.*, 2011).

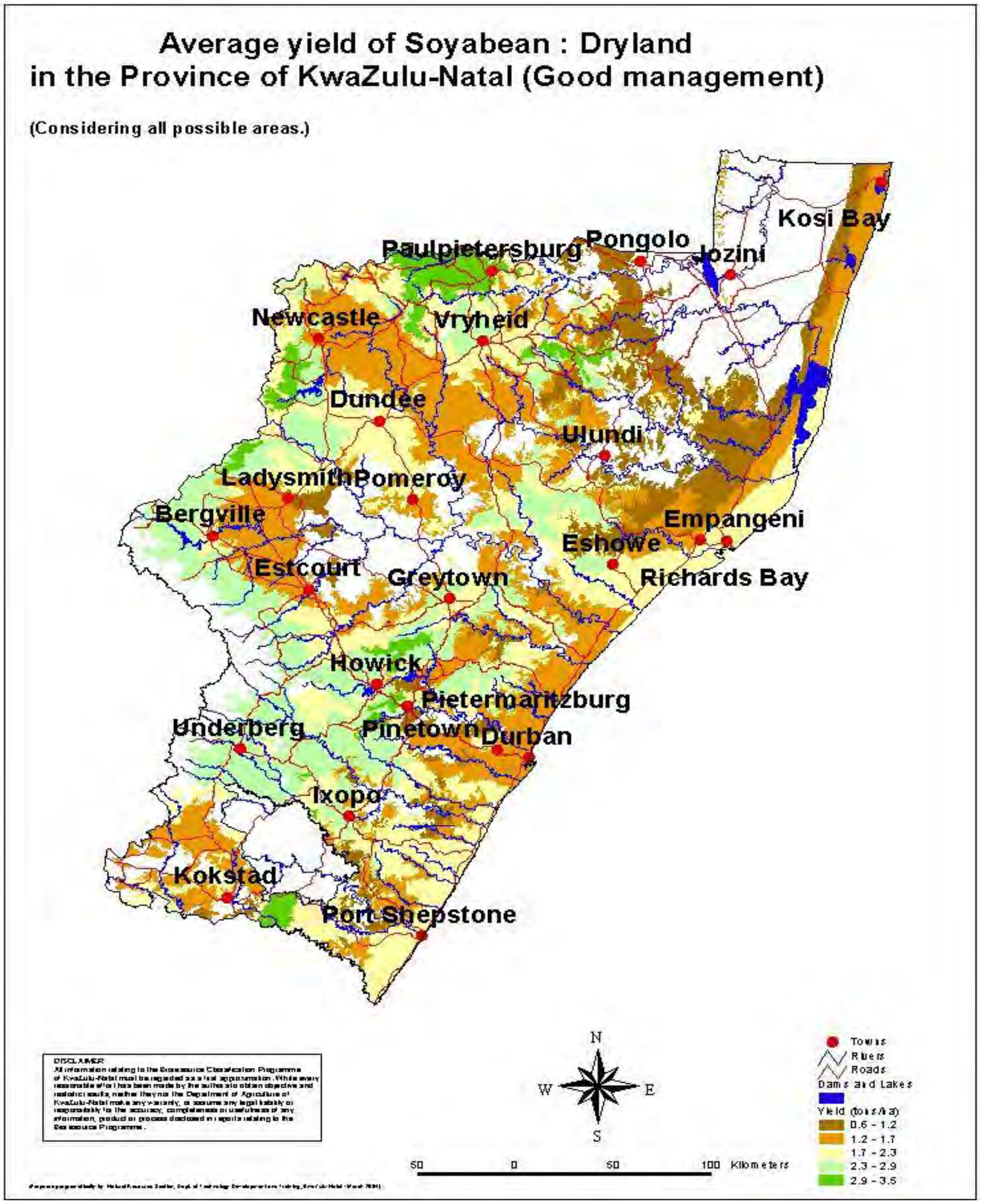

FIGURE 1.2 Average grain soybean yields expected under dry-land conditions with good management in KwaZulu-Natal, South Africa.

Acknowledgement: Natural Resource Section, KwaZulu-Natal Department of Agriculture and Rural Development

Temperature plays an important role in soybean growth. Each growth stage may differ with regard to its optimum temperature requirements, but 25°C is generally considered as the optimal temperature for soybean growth and production (Liebenberg, 2012), with the optimum temperature range being 20 - 30˚C (Lal *et al*., 2001). Temperatures higher or lower than this will retard vegetative growth (Liebenberg, 2012; Puteh *et al*., 2013). Puteh *et al*. (2013) reported that the number of pods $plant^{-1}$, seeds $plant^{-1}$ and 100-seed mass decreased significantly, whilst the percentage seedless pods increased significantly, as temperatures increased above 25°C during the reproductive stages. However, yield was only significantly reduced at temperatures above 30°C. The extent of the reduction in yield components and yield was influenced by the duration of the temperature exposure and the reproductive growth stage. The impact was greater when the plants were exposed to high temperatures from flowering until the fully expanded pod stage (R1-R5) than only at early flowering (R1-R2). As temperatures above 30°C regularly occur in South Africa from flowering through to maturity, yield reductions can be expected.

Soil temperatures at planting should preferably be above 15°C to ensure good germination (Liebenberg, 2012). Low temperatures will slow emergence and vegetative growth, delay maturity and reduce seed yields (Duxbury *et al*., 1990). In cool growing areas and with early planting dates, the plants will grow slower and therefore take longer to reach flowering and green pod harvest than in warmer areas and with later planting dates. With planting dates later than the optimum period (see below), the warmer conditions will shorten the growing period and the yield per plant will be reduced, due primarily to a reduction in the number of pods produced per plant (Zhang *et al.*, 2010; Liebenberg, 2012). Soybean is sensitive to day length (photoperiod) and therefore planting date will influence the growing-season length. A range of growing-season lengths occurs among the cultivars. Therefore, cultivar selection for the various areas is important. Short-season cultivars are better suited to the cooler production areas, such as the Highveld in South Africa, whilst long-season cultivars are better suited to the warmer areas. Growers can still plant up to the first week in January in the warmer areas in South Africa, but earlier maturing cultivars planted with a narrower row width and at a higher seeding rate are then recommended (Edwards *et al*., 2005; Christmas, 2008; Lal *et al*., 2008; Liebenberg, 2012). Haifeng (2006) reported that planting date was more important than plant density for pod yield.

Recommended planting dates for optimum production of soybean in South Africa are:
Cool areas: 20 October to 30 November
Moderate areas: 1 November to 15 December
Warmer areas: 15 November to 30 December (Liebenberg, 2012).

Comlekcioglu and Simsek (2009) observed that high temperatures and water stress negatively affect flowering and fertilization, increase flower abscission and the number of undeveloped pods, and reduce yield. The authors reported that green pod yield increased significantly as the amount of irrigation water applied increased and concluded that at least equal or excess of the evaporated water amount is required to produce high edamame yields. Demirtaş *et al*. (2010) reported that seed yield was not affected by drought stress during the vegetative development stages, whereas single or multiple drought stresses from flowering to seed enlargement stages reduced yield considerably. Seed size, sugar content and yield of edamame will be adversely affected by water stress (James, 2007). As the quality of edamame is important, it is advised that the crop be grown in high rainfall areas (> 800 mm $annum^{-1}$) under dry land conditions or under irrigation in lower rainfall areas or where the rainfall distribution is erratic during the growing-season (Duxbury *et al.,* 1990).

Yields will vary according to the environmental conditions experienced during the growing season. Carson *et al.* (2011) reported green pod yields that ranged from 5.61 t ha^{-1} to 8.43 t ha^{-1}, with a mean of 7.32 t ha^{-1}. Sharma and Kshattry (2013) recorded a mean green pod yield of 13 t ha^{-1} with a range from 11.58 t ha^{-1} to 14.46 t ha^{-1}, whilst Mentreddy *et al.* (2002) and Comlekciouglu and Simsek (2011) reported green pod yields up to 22 t ha^{-1} and 34 t ha^{-1}, respectively.

The crop can be established by hand or machine. The *Bradyrhizobium* bacteria required to effectively inoculate soybeans are not indigenous to South African soils and therefore inoculation of the seed at planting with the correct bacteria is essential (Lal *et al*., 2001; Liebenberg, 2012). In cool production areas, seedlings may be established in seedlings trays placed in tunnels and then transplanted into the field when the climatic conditions are warmer. The plants can also be grown in tunnels or in the field with plastic mulches (Bec *et al*., last accessed 24/08/2015).

1.4 MARKETING

The crop is marketed in three ways:

- Whole plants: the whole plant is cut at about 5 cm above the ground and about four to six plants are bunched together. The top leaves and small or damaged pods are removed. Alternatively, the whole plant with leaves, pods, stems and roots are packed in bundles or in 10 kg wooden boxes or cartons. The Japanese consider this the most preferred method as they believe it best preserves the pod quality.
- As green pods: the marketable pods (≥ 2 beans pod^{-1}) are removed from the stalks and packed and marketed fresh in plastic net bags. They may also be marketed frozen. Edamame is sometimes marketed as bunches of beans in pods, called “hands”.
- As green beans: after shelling, the green beans are marketed either fresh or frozen (Born, 2006). The beans from all the pods, including one-seeded pods, can be marketed. Mature dry beans can be harvested for the “food grade” market (Herman, 2010).

To maintain freshness, the plants or pods are harvested during the cooler hours of the day. In Asia, harvesting usually occurs at night (Lal *et al*., 2001). Depending on locality and climatic conditions, the green pod harvest window can be narrow, usually less than a week (Duppong and Hatterman-Valenti, 2005; Hamilton, 2007). Edamame should be harvested when the seed size is maximized, but before any yellowing of the pods occurs. This is critical for optimum texture and flavor (Herman, 2010). An indicator that this is about to happen is when the lower leaves of the plant start to yellow. The pods can be harvested by hand, which is preferred, but costly, or direct-harvested using a green bean (*Phaseolus vulgaris* L.) harvester (Nelson *et al*., 2002; Zandonadi *et al*. (2009); Herman, 2010). However, Born (2006), reports that these harvesters can cause 5% bruising and 24% marketable yield loss. Zandonadi *et al*. (2009) and Liebenberg (2012) reported that harvest efficiency will decline below 85% if the pods are positioned low on the plants as a result of low plant stands or short growing cultivars.

After harvesting, the marketable pods, which contain two or more beans, can be separated using mechanical sieves for sorting. To shell the beans, machinery with rollers is used to squeeze the beans out of the pods. The pods and the beans can be frozen and bagged for consumer use. Instant quick freeze (IQF) technology, which uses a combination of carbon dioxide and nitrogen, provides a quality frozen product, if the beans are harvested at the correct stage of development. Frozen edamame can be stored for long periods of time (Nelson *et al.*, 2002). Chilling beans for 3 to 10 hours after harvest helps preserve quality. Fresh pods and beans can be held in excellent conditions for several days using cold chain technology similar to that deployed for other vegetables (James, 2007).

1.5 USES

The green pods are usually boiled for a few minutes to ease shelling. The beans are then squeezed out of the pod and eaten like green peas (*Pisum sativum* L.). The pod is not eaten. The beans are larger (Zhang *et al.*, 2009), more tender, sweeter, have a nuttier flavour and are more digestible than grain soybeans (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007). The beans may be roasted and seasoned as a finger-food snack or included as a vegetable ingredient in stir fries, soups and salads (Mentreddy *et al*., 2002; Duppong and Hatterman-Valenti, 2005; Sanchez *et al*., 2005; Zhang and Kyei-Boahen, 2007). Edamame is sometimes referred to as "beer bean" because it is often eaten as a snack with a beer. In Japan, dark-seeded edamame is eaten as a dry bean at New Year celebrations (Miles *et al*., 2000).

Pod shattering at full maturity readily occurs with edamame. Seed losses will occur if seed producers do not harvest early enough (Zhang and Kyei-Boahen 2007).

Successful edamame production involves an integration of many management practices, including cultivar selection, seeding rate, planting time, inoculation, seed treatment, fertilization, irrigation, pest control, harvesting and seed storage.

Previous research on edamame in South Africa has been limited. Research on the following aspects was initiated at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), KwaZulu-Natal, South Africa:

1. Seeding rates
2. Cultivar evaluation
3. The effect of phosphorus and potassium levels on production
4. The effect of fungicide seed applications on plant stand
5. The evaluation of inoculants on production

1.6 SEEDING RATE

According to Lee *et al.* (2008), soybean yield is relatively insensitive to plant population with a wide range of seeding rates producing the same yield. Soybean has the ability to adjust its growth habit to account for various spatial distributions and therefore these plant characteristics will respond to various seeding rates in order to contribute to maximum yield (Suhre, 2012).

Recommendations for suitable plant populations to optimize edamame production are not consistent. In research work conducted by Sethakoon (1999), Lal *et al.* (2001), Kratochvil (2002), Nelson *et al*. (2002), Sanchez *et al.* (2005) and Sciarappa *et al*. (2007), row spacings of 0.15 to 0.75 m were used with plant populations varying from 43 000 to 430 500 plants ha^{-1}. Sethakoon (1999) obtained significantly higher yields at 400 000 and 266 666 plants ha^{-1} than at 200 000 and 160 000 plants ha^{-1}, but the number of pods $plant^{-1}$ decreased with increased plant population. Kratochvil (2002) reported that 430 000 plants ha^{-1} was too high for acceptable green pod production, but that 86 000 plants ha^{-1} produced yields that were low. Nelson *et al*. (2002) reported that marketable green pod yields increased with populations of 99 000 to 247 000 plants ha^{-1}, but the result was non-significant. Miles *et al.* (2000), Feibert *et al.* (2001) and Nelson *et al*. (2002) recommended seeding rates of 148 000 to 173 000 seeds ha^{-1}. Edwards *et al*. (2005) and Christmas (2008) recommended higher seeding rates for short-season cultivars.

Herman (2010) reported that edamame plants respond to lower plant populations by producing more branches. Christmas (2008) and Epler and Staggenborg (2008) reported a similar response with grain soybean and added that the number of pods on both the main stem and branches increased as plant populations decreased. Swathi (2009) measured a significant positive correlation between the number of branches $plant^{-1}$ and the number of pods $plant^{-1}$. Sethakoon (1999) and Haifeng (2006) reported that the number of edamame pods $plant^{-1}$ increased significantly as the seeding rate decreased. Epler and Staggenborg (2008) reported that the percentage of branch pods on each plant decreased as the plant population increased. The authors concluded that increased competition within the rows caused the plants to branch less and therefore produce less of the total yield from the branches.

The AVRDC – The World Vegetable Centre recommended that 100-seed mass (dry) of vegetable soybean must be ≥ 30 grams for export market requirements (Lal *et al.*, 2001). Herman (2010) found little change in seed size and seed number per pod, whilst James (2007) reported that seed mass decreased linearly as plant population increased from 50 000 to 400 000 plants ha^{-1}. However, from 50 000 to 200 000 plants ha^{-1}, James (2007) measured no decrease in seed size for the cultivar, C784. Epler and Staggenborg (2008) reported that seed mass influenced grain yield significantly, whilst Bekele and Alemahu (2011) reported that soybean seed yield was strongly correlated to the number of seeds plant^{-1}, pods plant^{-1}, seeds pod^{-1} and the number of days to maturity. The number of beans pod^{-1} is an important factor in edamame production, because the pods should contain ≥ 2 beans pod^{-1}, especially for the export market.

Plant height and bottom pod height are influenced by seeding rate, cultivar and planting date. Sethakoon (1999), Christmas (2008) and Epler and Staggenborg (2008) reported that plant height and bottom pod height increased significantly as the plant population increased, due to increased competition for sunlight among the plants. Swathi (2009) recorded a highly significant positive correlation between the number of days to 50% flowering and plant height. Therefore cultivars with longer growing-seasons tend to have taller plants, which may be prone to lodging and yield losses, especially if planted at high seeding rates (Christmas, 2008). Plant height and bottom pod height will shorten with delayed planting dates as a result of the warmer growing conditions, which shorten the growing period (Liebenberg, 2012; Sadeghi and Niyaki, 2013).

Bottom pod height is an important criterion for mechanical harvesting, because pods that are too close to the ground may not be harvested, resulting in yield losses (Zandonadi *et al.*, 2009; Liebenberg, 2012).

For grain soybean, Liebenberg (2012) recommended that lower seeding rates be employed in the warmer and drier areas of South Africa than in the higher rainfall areas or where irrigation is available. This recommendation could also apply to edamame. However, as quality is an important requirement with edamame production, it is recommended that the crop be irrigated in the warmer and drier parts of South Africa.

Row spacing is another management practice to consider. Narrower rows will result in quicker canopy closure, which will consequently reduce soil moisture loss through evaporation and reduce weed growth. Therefore, higher yields can be expected (Robinson and Conley, 2007). However, disease incidence may be higher (Liebenberg, 2012). De Bruin and Pedersen (2008 (b)) obtained significantly higher grain soybean yields when the rows were spaced 0.38 m apart compared to rows spaced 0.76 m apart.

Research conducted by Edwards *et al*. (2005) on grain soybean indicated that yield was optimized at 200 000 seeds ha^{-1} for long-season cultivars and at 600 000 seeds ha^{-1} for early-season cultivars. A positive correlation was reported between yield and plant population for the early maturity cultivars, but little response was measured for the long-season cultivars at plant populations beyond those that provided full canopy cover. Cultivars with lengthened reproductive periods usually produce more nodes, seeds and pods and therefore higher yields than short-season cultivars (Beuerlin, 2001). Yield is highly correlated to the number of seeds produced per unit area (Kantolic and Slafer, 2007). As quick canopy closure is important, short-season cultivars, which have short plant heights, benefit from narrower inter-rows and higher plant populations (Edwards *et al*., 2005; Christmas, 2008).

Due to warmer conditions when planting later in the season, soybean plants mature quicker and produce fewer pods plant^{-1}. Therefore higher plant populations may be required for late planting dates to compensate for the lower yield per plant (Lee *et al*., 2008; Zhang *et al*., 2010). However, Egli and Bruening (2002) and Zhang *et al*. (2010) reported that the yield of the short-season cultivars appeared to be insensitive to sowing date.

In studies conducted by De Bruin and Pedersen (2008 a; b) on grain soybean, higher yields were obtained at higher seeding rates, but the financial benefit was removed due to higher seed costs. A similar result may occur with edamame, especially as the seed cost is expected to be higher than that of grain soybean in South Africa.

1.7 CULTIVAR SELECTION

Soybean cultivars can display large fluctuations in their yielding ability when grown in different environments. Their adaptation to geographical areas is specific. Unlike other commonly cultivated crops, such as maize, soybean is sensitive to day length (photoperiodism) and a given cultivar will have a longer growing-season the further south it is planted in South Africa (de Beer, 2012).

Soybean plants make the transition from the vegetative growth phase to the flowering phase in direct response to the length of darkness in each 24 hour period, modified by temperature. As the length of the light period shortens, flowering is initiated. The exact date when flowering commences will depend upon the interaction between a cumulative photoperiod effect and the air temperature. Flowering date for a particular cultivar may therefore vary slightly each season.

Each cultivar has an optimum planting period in each specific location, which enables the plant to attain its optimum leaf area before flowering (Parsons and Birch, 1990).
Planting date will therefore influence the length of the growing-season and a given cultivar will flower much earlier should it be planted at a later date, due to warmer conditions. Prevailing temperature in a growing area will also have an effect. The growing-season will be much longer in cooler areas than in warmer areas (de Beer, 2012). In South Africa, August and September plantings will stimulate flower formation directly after emergence, because the day length is still too short. October plantings in warmer areas will result in lush growth and a low harvest index (the ratio of seed mass to total plant mass). Late plantings (January) will produce shorter plants with lower harvest potential and the number of days from planting to harvest will decrease (Zhang *et al*., 2010; Liebenberg, 2012).

The recommended planting dates for the cool, moderate and warm areas in South Africa apply to grain soybean (page 5). With edamame, considerations must be given to supplying fresh pods or beans to the market over as long a period as possible. Edamame cultivars with shorter growing-season lengths than grain soybean are therefore required (Feibert *et al*., 2001). Serial planting of a selection of cultivars with varying growing-season lengths will extend the harvest period and maximize profitability (Rao *et al.*, 2001; Herman, 2010; Zhang *et al.*, 2010).

Aside from the length of the growing-season, other factors to consider during edamame cultivar selection are:

- Seed size (≥ 25 g 100 seeds^{-1}, but ≥ 30 g 100 seeds^{-1} for the export market)
- Taste (sucrose levels)
- Yield potential
- Number of seeds pod^{-1}
- Number of pods plant^{-1}
- Pod and bean size and appearance
- Nutritional qualities, such as protein and oil content) (Mentreddy *et al*., 2002; Nelson *et al*., 2002; Born, 2006 and James, 2007).

Late-maturing cultivars are taller, have more nodes plant^{-1}, pods plant^{-1} and fresh green pod yield than the early maturing cultivars. Early planting will increase plant height, number of pods plant^{-1} and fresh pod weight. Short growing-season cultivars could be suitable for double-crop systems in South Africa (Egli and Bruening, 2000; Zhang and Kyei-Boahen, 2007).

Bekele and Alemahu (2011) reported that seed yield was significantly positively correlated to the numbers of seeds pod^{-1}, pods $plant^{-1}$ and seeds $plant^{-1}$, days to maturity and grain-filling period.

Soybean has mean oil and protein contents of 18% and 40%, respectively (Olabiyi *et al*., 2013), with ranges from 35% to 42% for protein content and from 12 to 22% for oil content, depending on cultivar and growing conditions (Filho *et al*., 2001; Popovic *et al.*, 2012). Seed protein content is negatively correlated to seed oil content and often to yield, whilst yield and oil content are usually positively correlated (Filho *et al.*, 2001; Chung *et al*., 2003; Filho, 2004; Bekele and Alemahu, 2011; Popovic *et al*., 2012). Filho *et al.* (2001) recorded a highly significant positive correlation between 100-seed mass and oil content, but a significant negative correlation between 100-seed mass and protein content. These traits are genetically set, but environmental conditions will affect the phenotypic response. Vollman *et al.* (2000) reported that protein content may be reduced due to climatic conditions, such as low soil or air temperatures and high rainfall during pod-filling, or insufficient nitrogen fixation. Popovic *et al.* (2013) reported that yield was positively correlated to the quantity and distribution of rainfall, but negatively correlated with temperature. Chung *et al.* (2003) stated that yield will decline if seed protein content is bred for at the expense of seed oil content.

1.8 SOIL FERTILITY AND FERTILIZATION

Soybean tolerates a wide range of soil conditions, but yield best on well-drained, fertile lands (Birch *et al.*, 1990). They have a considerable macronutrient requirement, which varies according to soil and climatic conditions, cultivar, yield level, cropping system and management practices. With vegetable soybean, yield, flavour and quality are influenced by cultivar selection and soil fertility (Konovsky *et al.*, 1994).

Research conducted in KwaZulu-Natal in the mid-1980s demonstrated that grain soybean responded strongly to direct fertilization, especially where the soil levels of phosphorus (P) and potassium (K) were medium to low (Birch *et al*., 1990). Imas *et al.* (2007) stated that a 3 t ha^{-1} soybean crop is able to extract 240 kg of nitrogen (N), 45 kg of P and 100 kg of K. The withdrawal of nutrients per ton of soybean seed was approximately 60 kg of N, 5 - 6 kg of P and 18 - 19 kg of K. Approximately 70% of the N and P, and 55% of the K taken up by the plant is removed from the land in the seed (Birch *et al.*, 1990). Tables 1.1 and 1.2 provide guideline recommendations of K and P fertilization rates for various soil K and P levels and potential yields under conditions in KwaZulu-Natal, South Africa.

TABLE 1.1 Guidelines for K-fertilization of soybeans

Soil K	**K-application for yield potential (t ha^{-1})**		
	1	**2**	**3**
mg kg^{-1}		**(kg ha^{-1})**	
20	20	30	60
40	16	23	47
60	13	19	39
80	11	17	34
100	10	15	31
120*	0	0	0

(Fertilizer Society of South Africa, 2007. Adapted for a lower removal figure)

* No K reaction expected

TABLE 1.2 Guidelines for P-fertilization of soybeans

Soil P (Bray1)	**P-recommendation for yield potential (t ha^{-1})**		
	1	**2**	**3**
mg kg^{-1}		**(kg ha^{-1})**	
5	20	40	60
10	17	31	45
15	15	25	35
20	10	20	30
25	11 (6)*	19 (12)*	28 (18)*
30	10 (5)*	18 (10)*	26 (15)*

(Fertilizer Society of South Africa, 2007. Adapted for a lower removal figure)

* Maintenance fertilization if removal of 6 kg P ha^{-1} by soybeans is accepted

Soybean, if effectively inoculated with *Rhizobium* bacteria at planting and grown in soils with a satisfactory pH (6.0), can supply its own N requirements. If well nodulated, yields as high as 3 – 4 t ha^{-1} can be produced. N fixation is, however, inhibited by high levels of mineral N in the soil, by drought stress and by poor soil aeration. K is very important to N fixation, because it stimulates early root growth, thus ensuring early nodulation. In addition, K provides the roots with the necessary carbohydrates for optimum nodule functioning. Studies have shown that nodule number and weight and total N accumulation in the plant increased as the supply of K increased (Imas *et al.*, 2007).

K not only improves yields and water use efficiency, but also benefits various quality aspects. Oil and protein content are improved and larger seeds are produced (Chauhan, 2007), which are essential factors in the production of quality edamame. Drought tolerance and the plants" resistance to pests and diseases are also improved (Imas *et al.*, 2007: Tomar *et al.*, 2007). Isoflavones, which are associated with the prevention and treatment of cancer, diabetes, hypertension and heart disease, have been found to increase with increased levels of K fertilization in soybeans (Rajcan *et al.*, 2000; Chauhan, 2007).

The critical level of soil K for soybean has been found to be 80 mg L^{-1} (Birch *et al.*, 1990). K is not immobilized in most South African soils and soybean is able to utilize K-reserves well. In KwaZulu-Natal soybean does not react to K fertilizer applications when the soil K-status is above 90 mg kg^{-1}, but where a K-deficiency occurs, soybeans react well to K-fertilization (Liebenberg, 2012). Soils which have been analyzed to show medium to low levels of available K should receive 30 to 60 kg ha^{-1} of K, respectively (Birch *et al*, 1990). However, as soybeans are generally used in a rotation with maize and remove fairly large quantities of K, the Fertilizer Advisory Services (Fertrec) of the KwaZulu-Natal Department of Agriculture and Rural Development"s recommendations use a critical soil K level of 100 mg L^{-1} to ensure that the maize crop receives sufficient K.

K-deficiency symptoms are characterized by yellowing of the leaf margins. These generally appear between late flowering and early pod-fill (Liebenberg, 2012). As with maize, these deficiency symptoms first appear on the lower leaves. With maturity, the deficiency symptoms expand to leaves closer to the top of the canopy.

P is essential for soybean growth, pod development, yield and seed quality and can be absorbed until late in the pod-fill stage (Liebenberg, 2012). A lack of this element may prevent other nutrients from being absorbed by the plants (Sharma *et al.*, 2011). Waluyo *et al.* (2004) reported that P increased the number of nodule primordial and therefore had an important role in the initiation of nodule formation. Kumaga *et al.* (2004) and Bekere and Hailemariam (2012) reported that the number of nodules $plant^{-1}$ increased with the application of P. Zarrin *et al*. (2007) reported that the combination of R*hizobia* and P increased nodulation and seed yield. P deficiency is characterized by paler and smaller leaves, shorter plants and premature defoliation of the lower leaves (Liebenberg, 2012). Oil and protein content may also be affected (Yu *et al.*, 2008; Win *et al.*, 2010; Liebenberg, 2012), although Nedić (2005) found no effect. Zheng *et al.* (2010) found that soybean yields improved with P application under drought stress conditions.

Shahid *et al.* (2009) reported that plant height and the number of branches plant^{-1} were significantly higher at 75 and 100 kg ha^{-1} P than at 0 kg, 25 kg and 50 kg ha^{-1}. The number of pods plant^{-1}, pod length, number of seeds pod^{-1}, seed yield and oil yield were significantly higher at 100 kg P ha^{-1} than at all the other P rates. Sharma *et al.* (2011) found significant increases in plant height, number of pods plant^{-1} and grain yield with increased P application rates (0 kg, 30 kg and 60 kg ha^{-1}), but the response varied with soybean variety.

In KwaZulu-Natal soybean is widely grown in soils where P is strongly adsorbed by clay in the soil, making it unavailable to the crop (Birch *et al.,* 1990 and Liebenberg, 2012). Approximately 6 kg P is removed per ton of soybean seed (Liebenberg, 2012). Even where target P levels are met, it is recommended that 20 kg ha^{-1} P be applied at planting, preferably band-placed along the row, although Mallarino (2006) found no response in yield to band or broadcast application. Soils with medium to low available P levels should receive a minimum of 20 to 40 kg P ha^{-1} (Birch *et al.,* 1990). However, the combination of N, P and K must be balanced for optimum yield to be achieved.

Birch *et al.* (1990), Mahamood *et al.* (2009) and Sharma *et al.* (2011) reported that certain grain soybean cultivars respond differently to inadequate P levels. Nwoke *et al.* (2009) and Wang *et al.* (2010) suggested that P-efficient cultivars could, therefore, play a major role in increasing soybean yield. Similarly, edamame cultivars may yield optimally at different levels of fertility.

Soybean is more tolerant of aluminium than maize, provided the seed contains sufficient molybdenum. Soybean roots are therefore able to penetrate highly acidic subsoils and utilize the subsoil moisture present. Consequently soybean can survive drought periods better than maize in South Africa (Liebenberg, 2012).

Soybean leaf analyses are effective in identifying nutritional problems. Leaf samples must consist of leaf blades without the petioles. The uppermost, mature (fully expanded) trifoliate leaves should be picked. Birch *et al.* (1990) recommended that the leaves be picked after flowering when the upper part of the plant bears young pods and the lower pods are fully elongated. However, Liebenberg (2012) recommended that the leaves be picked during the late flowering stage and early pod fill stage. Approximately 50 to 100 randomly selected leaves should be collected and dried as rapidly as possible soon after collection. Leaves covered with dust should be washed or dusted. Table 1.3 provides sufficiency ranges and excessive levels for various micronutrients in soybean leaves.

TABLE 1.3 Sufficiency ranges for soybean leaves sampled prior to pod set (Small and Ohlrogge, 1973) and preliminary Cedara sufficiency ranges using leaves sampled after flowering as prescribed and excessive (toxicity) levels (Ohlrogge and Kamprath, 1968)

Element	**Sufficiency range**		**Excessive (>)**
	Ohio, USA	**Cedara**	**USA**
Micronutrient		**(%)**	
Nitrogen	4.26 – 5.50	4.00 – 5.50	7.0
Phosphorus	0.26 – 0.50	0.26 – 0.50	0.8
Potassium	1.71 – 2.50	1.40 – 2.50	2.7
Calcium	0.36 – 2.00	0.36 – 2.00	3.0
Magnesium	0.26 – 1.00	0.22 – 1.00	1.5
Sulphur	0.30 – 0.60	0.20 – 0.60	
Micronutrient		**(mg kg^{-1})**	
Manganese	21 - 100	21 - 100	250
Iron	51 - 350	51 - 350	500
Boron	21 - 55	21 - 55	80
Copper	10 - 30	10 - 30	50
Zinc	21 - 50	21 - 50	75
Molybdenum	1 - 5	1 – 5	10

1.9 FUNGICIDE SEED TREATMENT

Researchers have reported poor emergence and low plant populations with edamame that varied among the seasons and the cultivars (Miles and Sonde, 2002; Hatterman-Valenti, 2003; Duppong and Hatterman-Valenti, 2005; Sanchez *et al.,* 2005; Hamilton, 2007). Many factors cause poor emergence. Seed quality and vigor will decline when high temperatures and/or moisture stress (drought) occur during pod-fill and therefore emergence will be affected (Spears *et al*., 1997; Egli *et al.*, 2005; Ren *et al.*, 2009; Khan *et al*., 2011; Liebenberg, 2012). Early- and medium-maturing cultivars may be more susceptible to seed deterioration than later-maturing cultivars, because they are exposed to higher temperatures and more rainfall during pod-fill. These hot and humid conditions may be ideal for an infection of the pod fungal disease, *Phomopsis longicolla* Hobbs, which results in seed rot (Li and Chen, 2013). Spears *et al*. (1997) reported that seed quality was lower when the plants were exposed to high temperatures during pod development, but not from physiological maturity to harvest maturity. Therefore, the later soybean is planted in the season, the better the seed quality will be, because the plant will mature in drier and cooler conditions (Khalil *et al*., 2001). The chance of seed infection by *Phomopsis* will increase the longer the mature crop is left in the field before harvesting, especially if warm and wet conditions prevail (Gleekia-Kerkula, 2012; Liebenberg, 2012).

Poor post-harvest storage and seed age will also affect seed quality and emergence. To ensure good viability and vigor, Mbofung *et al*. (2013) recommended that soybean seed should have a moisture content ≤ 10% during storage and that the storage temperature and relative humidity should be maintained at 10°C and below 40%, respectively. Treatment of seed with a fungicide before storage will also improve viability. According to Shelar *et al*. (2008) and Gleekia-Kerkula (2012) soybean genotypes differ in their ability to maintain seed longevity. Genotypes with high oil contents and low protein contents deteriorate most rapidly. Shelar *et al*. (2008) further observed that smaller soybean seeds had superior storability than larger seeds, which edamame have.

Germination may also be affected by soil and air temperature, soil moisture conditions at planting, soil crusting and planting depth (Miles and Sonde, 2002). When planted early, soybean seed may take longer to germinate, due to cooler temperatures, and therefore be exposed to soil-borne pathogens for longer, which could result in lower emergence and plant stand (Lundvall *et al*., 2001).

Seed rot and seedling diseases can be caused by P*ythium* and F*usarium* species and R*hizoctonia solani* Kuhn, which are present in all soils. Their inoculum levels can build up due to adverse conditions, such as excessive rain, cold or heat, drought, herbicide damage and poor fertility, and a lack of suitable crop rotation. Dark brown to red colouring of the stem and main root is an indication of a seedling disease. The seeds and seedlings may be attacked pre- and post-emergence. The seedlings may sometimes emerge, but then die due to rotting of the main root or stem. Suitable fungicides applied to the seed or in the row will help to protect the seed during germination only. There is no control method once the disease has set in (Liebenberg, 2012).

Charcoal rot is another disease that can affect seedlings, especially in the hotter production areas. The causatal organism is *Macrophomina phaseolina* (Tassi) Goid. Infected seedlings may show a reddish brown discolouration on the hypocotyls emerging above the soil. If root infection occurs, a dark brown to black discolouration can be seen at and above the soil surface. Seedlings may die, especially when hot, dry conditions cause stress to the plants. Infection can occur from germination up to the pod stage (Liebenberg, 2012). No fungicides are available to control the disease.

Fusarium blight or wilt and Fusarium root rots are caused by *Fusarium* oxysporum Schlecht and *Fusarium solani* Mart. Fusarium root rots develop on seedlings and young plants during cool weather (14°C) and infection can be severe when the soil is saturated. Germination may be slow and senescence can occur before emergence. Infected seedlings are stunted and weak (Liebenberg, 2012).

Phytophthora megasperma Drechs var. *sojae* Hildeb will cause root and stem rot at any stage during the growing season. Seed and seedling rot, and wilt can occur during waterlogged conditions. The application of registered fungicides to the seed or planting furrow will assist in controlling the disease in tolerant cultivars. The crop should be planted on well-drained lands where crop rotation is practiced (Liebenberg, 2012).

Diaporthe phaseolorum var. *sojae* Lehman, *Diaporthe phaseolorum* var. *caulivora* Athow and Caldwell and *Phomopsis longicolla* Hobbs occur in a complex, causing Phomopsis seed rot as well as pod and stem blight. The disease is an important cause of poor grain quality and diseased seed. Warm, wet weather during the pod-fill and maturity stages promotes seed infection, which will have a negative effect on subsequent germination. The stems, petioles, pods and seeds are initially affected without symptoms being displayed. Spore-carrying structures of the fungus become visible in rows on the stems and pods of the infected plants as they dry out. Red or brown lesions of varying sizes may appear on the cotyledons of infected seeds and small reddish brown stripes can appear on the hypocotyl just below or at the soil surface. Crop rotations with non-leguminous crops and deep ploughing of infected residues will assist in reducing future infection (Liebenberg, 2012). Planting should be planned to ensure that seed matures during a dry period. Early- and medium-maturing cultivars may be more susceptible to seed deterioration than later-maturing cultivars, because they are exposed to higher temperatures and greater humidity. Therefore, for quality seed production, late planting dates are recommended (Khalil *et al*., 2001). A suitable fungicide application during mid-flowering to late pod-fill will also reduce seed infection (Liebenberg, 2012).

Six *Pythium* species are involved with seed decay and root rot. Infection is encouraged by saturated soil after planting and temperature. However, some *Pythium* species prefer warm conditions, whilst others prefer cool conditions. Seed infected before germination is soft and rotten and has soil attached to it. If infection occurs after germination the seedlings may not emerge or develop only a short, discoloured root. The symptoms resemble those caused by other fungi, especially *Fusarium* and *Phytophthora* spp. Wilting of the seedling or plant occurs due to root damage. A seed application of a registered fungicide will help to control the disease. Irrigation should be avoided within 10 days after planting (Liebenberg, 2012).

Rhizoctonia solani affects the seeds and the roots. The seeds rot before emergence and therefore the first observed symptom is wilting after emergence and before the first trifoliate leaf stage. Sunken reddish brown lesions on the hypocotyl at soil level are evident. Infected seedlings may either die off or survive. Infected plants will have weak root systems and be stunted and chlorotic. Stress caused by heat, drought, herbicide damage and poor fertility will aggravate the infection. Seed treatment with a registered fungicide will assist in preventing the disease. Xue *et al.* (2006) reported that thiram and other fungicides applied as seed-coatings, were effective in controlling R. *solani* when applied as seed coatings and improved plant stand and yield. Crop rotation is ineffective in controlling the disease, because the pathogen has a wide host range, including most commercial crops. Tillage after harvesting will break down fungal colonies and reduce fungal survival. Tillage between the rows will improve soil aeration and encourage new root growth (Liebenberg, 2012).

To market edamame pods early, farmers may be enticed to plant early in the season, when the soil may still be cool and wet, which could delay emergence and subject the seed to greater risk of disease infection (Zhang *et al.*, 2010). The application of fungicide seed dressings at planting may therefore be necessary.

However, the efficacy of inoculation can be lowered if applied to fungicide treated seed (Campo *et al*., 2009). Research indicates that the use of an inoculant with a peat base, applied less than 10 hours before planting, is compatible with most commonly used fungicides. Fungicides vary in their detrimental effect on nodulating bacteria. The following fungicides are considered detrimental: captan, copper based compounds and oxycarboxin (Liebenberg, 2012). Kaur *et al*. (2007) reported that carbendazim is toxic to nodule bacteria, whilst captan was observed to be compatible with them. The authors suggested that soybean seed treatment with captan should be conducted routinely. Liebenberg (2012) found that benzimidazole, thiram and dithiocarbamate have little effect on nodulation even after long contact hours. However, Campo *et al*. (2009) reported that the survival of bradyrhizobial bacteria on soybeans seeds were severely affected by fungicides, including benomyl, captan, carbendazim, carboxin, difenoconazole, thiabendazole, thiram and tolylfluanid. Mortalities up to 62% after only 2 hours and of 95% after 24 hours were reported. The fungicides reduced nodule number, total nitrogen in the grains and decreased yield by up to 17%. The toxic effects were more drastic in sandy soils without previous soybean inoculation, reducing nodulation by up to 87%. Soils where *Bradyrhizobia* were present were also negatively affected. The authors suggested that fungicides should only be used when the seeds or soil are contaminated with pathogens. Andrés *et al.* (1998) also reported that thiram was detrimental to *Bradyrhizobia*.

Campo *et al.* (2010) reported that the application of agrochemicals affected nodulation when applied together with peat or liquid inoculant to the seeds. The negative effects were more pronounced when the crop was grown on sandy soils and where no established populations of *Bradyrhizobia* were present or when planted under unfavourable (dry) climatic conditions. The authors found that in-furrow inoculation was as effective as traditional seed inoculation and that this method minimized the negative effects of seed treated with fungicide and micronutrients prior to planting.

Zilli *et al*. (2009) reported that the fungicide combination of carbendazim + thiram reduced nodule number plant^{-1} significantly (> 50%) when applied to seed inoculated with *B. elkanii* and *B. japonicum*. However, despite the reduction in nodules, no significant differences in plant dry matter weight, total N in the plant and grain, and grain yield were measured. In a second experiment carbendazim + thiram did not significantly reduce nodulation, grain yield and grain N content of the plants inoculated with *B. japonicum.* However, carbendazim + thiram reduced nodulation when plants were inoculated with *B elkanii* strains SEMIA 5019 and SEMIA 587. Grain yield and grain N content were significantly lower when SEMIA 587 was applied. These results indicated that certain strains of inoculant may be more sensitive to fungicides than others. However, the AVRDC – The World Vegetable Centre in Taiwan recommends the use of thiram and captan as seed dressings for the protection of vegetable soybean against soil-borne fungal diseases (Lal *et al.*, 2001).

Strains of *Trichoderma* species are fungi that may be used as bio-fungicides for the suppression of various seed- and soil-borne fungal diseases in various crops (Tančić *et al.,* 2013). These fungi are commercially marketed as biopesticides, biofertilizers and soil amendments (Vinale *et al*., 2008), whilst some strains have shown growth promoting properties, which enhance germination, shoot and root length and vigour (Mukhtar *et al*., 2012; Tančić *et al.,* 2013). Mukhtar *et al*. (2012) reported that the application of strains of *Trichoderma harzianum* Rifai and *Trichoderma hamatum* Rifai to soybean seeds resulted in higher germination rates (96%) when compared with other *Trichoderma* strains and the control (76%). Asaduzzaman *et al*. (2010) reported that all the *T. harzianum* strains evaluated enhanced germination of chili seeds, with the strain *T. harzianum* IMI 392432 causing the earliest and highest germination. *Trichoderma* species have been registered mainly as effective biological antagonists of soil-borne pathogens and diseases, such as *Sclerotinia sclerotiorum* de Bary*, S. minor* Jagger*, M.* phaseolina (Tassi) Goid*, R. solani* Kuhn*, Fusarium spp., Pythium spp, and Phytophthora spp.* (Tančić *et al.,* 2013) and nematodes (Olabiyi *et al*., 2013).

In pot trials conducted by Bosse *et al.* (2011) to evaluate the use of Eco-T® (active ingredient *T. harzianum* strain kd at 2 x 10^9 conidia g^{-1}) and silicon to prevent *Rhizoctonia* and *Pythium* root rot in soybean, the combined application of Eco-T® and silicon resulted in significant increases in soybean shoot biomass, root area, root biomass and root length compared to the control treatment. The authors concluded that Eco-T® protected the seed against *Rhizoctonia* and *Pythium* before root development, but once the roots have developed, the silicon taken up by the plants prevents the pathogens from penetrating the root area and possibly induced host defense reactions.

In a study conducted by Abudulai *et al*. (2014) with soybean grown in a poor fertility soil in Ghana, plant growth in the first 55 days after emergence was significantly taller when the inoculants, Eco-T® (*T. harzianum*) and Eco-Rhizsoy® (*Bradyrhizobium japonicum* strain WB74), had been applied compared to the uninoculated treatment. However, co-inoculation of the two products did not increase plant growth above the single inoculant treatments, but the yield was significantly higher. N"Cho *et al.* (2013) reported a similar increase in yield with co-inoculation of Eco-T® and the *Bradyrhizobium* strain, RACA 6. In a study conducted by Du Rand and Laing (2011) at Ukulinga and Baynesfield in KwaZulu-Natal, no interaction between Eco-T® and Eco-Rhizsoy® was measured and nodulation levels were similar, but the highest yields were obtained with this combination.

1.10 SEED INOCULATION

The soybean plant can utilize N from several sources, including mineralized N, residual soil N and N fertilizer (Emam and Rady, 2014), but also has the ability to biologically fix atmospheric nitrogen as a result of a symbiotic relationship between itself and *Bradyrhizobium* (*B*) bacteria when they are present in the soil and are compatible. These bacteria include *B. japonicum* Kirchner, *B. elkanii* Kuykendall and *B. liaoningense* Xu (Salvucci *et al*., 2012). In lands where soybean has not been grown before, plant height, canopy spread, leaf area, number of pods plant^{-1}, pod weight, seeds pod^{-1}, seed weight and, consequently, yield, will increase significantly when seed is inoculated with rhizobia (Solomon *et al*., 2012; Lamptey *et al*., 2014). The *Bradyrhizobium* bacteria required to effectively inoculate soybean are not indigenous to South African soils and therefore inoculation with the correct bacteria is essential. *B. japonicum* is usually used in South Africa (Liebenberg, 2012). Zarrin *et al*. (2007) and Solomon *et al*. (2012) reported differences in nodulation and seed yield among *B. japonicum* strains.

The bacteria invade the young roots from seed germination and feed on carbohydrates supplied by the plant. The bacteria multiply and are housed in nodules, which form on the roots within one week after seedling emergence. Nodules are formed during much of the plant‟s life. Active fixation begins in the V2 and V3 vegetative growth stages, when two or three sets of trifoliate leaves have unfolded, and continues until the reproductive growth stage R5, pod-filling. Active nodules have an internal pink colour and can remain active for six to seven weeks before they senesce (Pedersen, 2007).

The soybean plant‟s demand for N is highest from the R5 to the R8 stage, harvest maturity, (Pedersen, 2007). When biological nitrogen fixation (BNF) works well, the bacteria in the root nodules can supply the total nitrogen requirement of the crop. The cost of production is therefore reduced, because the application of expensive nitrogen fertilizer is unnecessary.

Soybean yields can be significantly increased through rhizobial inoculation where soil nitrogen is limited. Duxbury *et al.* (1990) and Ohyama *et al*. (2011) stated that approximately 80 – 90 kg of N is required to produce one ton of soybean seed. A 3 t ha^{-1} crop will therefore use 240 - 270 kg N ha^{-1}. Abendroth *et al*. (2006) estimated the nitrogen requirement could be as high as 350 kg ha^{-1}, whilst Unkovich and Pate (2000) reported that up to 450 kg N ha^{-1} can be fixed by soybean plants.

BNF, however, depends on environmental factors, resulting in variations in nitrogen fixation from 60 to 360 kg ha^{-1} N (Liebenberg, 2012). Dry soils and high soil temperatures will destroy the *rhizobia* (Hungria and Vargas, 2000), as will waterlogging (Amarante and Sodek, 2006). Poor nodulation will occur in soils with a pH below 5.2 (Liebenberg, 2012) and in soils with low P (Kumago *et al.*, 2004; Zarrin *et al.*, 2007; Bekere and Hailemariam, 2012) and K (Imas *et al*., 2007). The application of agrochemicals, fungicides and micronutrients to the seed will further negatively affect nodulation, especially when applied soon after planting (Campo *et al.*, 2010).

The uptake of fixed nitrogen by the plant may meet 60% – 89% of the total demand (Abendroth *et al*., 2006). However, nitrate in the soil can reduce nodule formation and activity and accelerate nodule senescence, especially when available in large quantities (Ohyama *et al*., 2011 and Emam and Rady, 2014). Campo *et al.* (2010) reported that the application of 200 kg N ha^{-1} significantly reduced soybean nodulation and resulted in lower yields, which were similar to those obtained from non-inoculated seed. If sufficient mineral N is present in the soil, the plant will give preference to soil-N and not from nitrogen-fixation nodules. With successful nodulation, the application of nitrogen fertilizers does not give a significant yield increase in soils with clay contents between 10% and 70%. Fertilization at planting with 15 kg N ha^{-1} may be beneficial in soils with clay contents below 10% (Liebenberg, 2012). Emam and Rady (2014) reported that the application of 60 kg ha^{-1} N to soybeans grown in a soil with 11% clay significantly increased yields. With an application of 180 kg N ha^{-1}, Emam and Rady (2014) reported no nodulation, but the yields were significantly higher than when inoculation was applied. In sandy soils, which have low organic matter contents (naturally less than 10 g kg^{-1}), and where the absence of effective BNF bacteria for the crops exists, seed inoculation with *Bradyrhizobium* strains is highly effective. In an experiment conducted by Zilli *et al.* (2009) in a soil with low organic matter and no *Bradyrhizobia* present, soybean yields increased significantly from 2.4 t ha^{-1} when no inoculant was applied to 4.1 t ha^{-1} and 4.0 t ha^{-1} when *B. elkanii* and *B. japonicum* were applied, respectively.

Under favourable conditions, nodulating bacteria can remain in the soil for several years, despite soybean having not been subsequently grown in the land (Liebenberg, 2012). Some research suggests that successive inoculant applications can increase yields by 4 to 5%, but usually the response is only 1 to 2% (Conley and Christmas, 2006). However, Pedersen (2007), Campo *et al.* (2010) and Jordan (2010) found no significant increase in yield where established *Bradyrhizobia* populations already existed. At R40.00 for a 250 g sachet, which will inoculate 25 kg of seed (H. van Vuuren, Soygro (Pty) Ltd. representative, personal communication), the cost of the inoculant is low and therefore regular inoculation is advised (Liebenberg, 2012).

Current recommendations are to inoculate the seed if:

a) the field has never been planted to inoculated soybeans
b) soybeans have not been grown in the field in the past three to five years
c) the soil pH is below 6.0
d) the soil has a high sand content
e) the field has been flooded for more than a week, creating anaerobic conditions (Pederson, 2007).

Unsatisfactory and ineffective nodulation will result in low nodule counts and the absence of a pink or red appearance within the nodules, which indicates that the nodules are active. Typical nitrogen deficiency symptoms of yellowed leaves will be evident (Liebenberg, 2012).

Additional benefits of biological nitrogen fixation are:

- The fixed nitrogen is in an organic form and cannot leach out.
- Biological nitrogen does not acidify the soil as fertilizer does, nor does it pollute surface and underground water sources.
- The supply of nitrogen to the plant is continuous and utilized directly by the plant.
- There is less foliage growth in comparison with soybeans grown with nitrogen fertilizers. Plants using nitrogen fixation transpire less and are more drought-tolerant.
- The plants have improved disease resistance due to the action of phyto-alexin, a chemical ensuing from nodulation with nitrogen–fixing bacteria (Liebenberg, 2012).

Porter *et al.* (1997) reported that residual biological nitrogen from the soybean crop can have an average yield increasing effect of 13% on a subsequent maize crop. The relative increase in yields of both maize and soybeans in an annual rotation compared with monoculture was almost double in low-yielding environments than in high-yielding environments. In low-yielding environments, the yield advantage of an annual maize and corn rotation compared to monoculture was frequently greater that 25%.

Nodulation differences among soybean cultivars have been observed (Salvucci *et al.*, 2012; Solomon *et al.*, 2012), whilst Salvucci *et al.* (2012) reported that cultivar growing-season length had no effect on cultivar nodulation ability.

1.11 ECONOMICS

There is no known commercial production of edamame in South Africa. Therefore determining the profitability of edamame in South Africa is based on estimations. The financial success of a crop will be governed by the forces of supply and demand. As the majority of the people in South Africa are unaware of edamame, an awareness campaign highlighting the health benefits and uses of this high protein crop will be required to create a demand. Large chain stores will need to be guaranteed a continuous supply of edamame for at least nine months of the year. This is possible if the crop is frozen. The cultivars available are non-GMO and can be grown organically. Higher prices can then be asked.

Grain soybean is successfully grown in KwaZulu-Natal under dryland conditions in the higher rainfall areas and under irrigation in the drier areas and/or where erratic rainfall is expected. Based on budgets developed by the Agricultural Economics Section of the KwaZulu-Natal Department of Agriculture and Rural Development, in the production year 2014/15, a 2 t ha^{-1} grain soybean crop produced under dryland conditions at a total allocatable variable cost of R6 800.00 ha^{-1} and sold at a price of R5 000.00 ton^{-1}, a gross margin above total allocatable variable costs of R3 200.00 ha^{-1} will be achieved. A 3.5 t ha^{-1} grain soybean crop produced under irrigation at a total allocatable variable cost of R9 100.00 ha^{-1} and sold at a price of R5 000.00 ton^{-1}, a gross margin above total allocatable variable costs of R8 400.00 ha^{-1} will be obtained. When soybean is grown under no-till conditions, lower fuel, repairs and maintenance costs will be incurred, which will increase the profitability.

Apart from seed costs, which may be higher for edamame than for grain soybean, the costs incurred with growing the crop may be similar. However, labour costs will be considerably higher with edamame when harvested manually (Zhang and Kyei-Boahen (2007). Machine harvesting with a green bean harvester will definitely be more economical (Born, 2006). However, harvest efficiency can vary from 54% to 85% depending on plant spacing and height (Zandonadi *et al*., 2009). Therefore, the market price of edamame will have to be high enough to ensure profitability. In a budget compiled by Ernest (2001), projected net returns of \$400 - \$2500 $acre^{-1}$

could be achieved. These returns translate to R12 300 – R30 750 ha^{-1} at the exchange rate of R12.30/$. Therefore, the returns per hectare could be more than twice that of grain soybean.

In an economic viability study conducted by Shockley *et al*. (2011), a market price of R11.40 kg^{-1} for organically grown edamame was required at the time of the study for farmers to switch from grain soybean to edamame. The authors calculated that greater maximum net returns could be achieved with edamame than with grain soybean, but cautioned that there could be greater risk involved with edamame production, because of the much higher quality requirements.

The manner in which the crop is marketed may also influence profitability. As mentioned on page 6, the crop can be sold either as whole plants, green pods or green beans. The Japanese consider the marketing of whole plants as the most desirable, because the pod quality is preserved and therefore higher prices can be obtained (Born, 2006). Harvesting costs will be reduced, because less labour will be required to remove the pods from the plants. However, when bundled and packed into wooden boxes or cartons, an additional packaging cost will be incurred. Small-scale farmers in KwaZulu-Natal may prefer to market edamame in bunches as it would be the easiest and cheapest method. When sold as shelled green beans machinery and additional labour costs will be incurred.

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FIGURE 1.3 Edamame plant with pods, which are not yet ready for harvesting.

FIGURE 1.4 Edamame pods and beans (Photo courtesy of Fotosearch®)

CHAPTER 2

EFFECT OF SEEDING RATE ON VEGETABLE SOYBEAN PRODUCTION

2.1 ABSTRACT

Vegetable soybean (edamame) is a little known crop in South Africa, but this high-protein oriental staple could be suitable for local small-scale and commercial production. The seeds are larger, milder-tasting and more tender than grain soybeans. The pods are picked when they are still green and the beans have developed to fill 80 to 90% of the pod. The immature bean seeds are usually eaten like green peas. Four cultivars, AGS 352, AGS 353, AGS 354 and Lightning, were hand-planted in 0.75 m wide rows at four seeding rates, 200 000, 300 000, 400 000 and 500 000 seeds ha^{-1}, at the Cedara Research Station, KwaZulu-Natal, South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The trial was planted four times, once in 2005 and 2006 and twice in 2007. Seeding rate had no significant effect on seed yield. Due to poor emergence and hail damage, mean plant population ranged from 121 700 to 252 360 plants ha^{-1}. Plant population was significantly negatively correlated to yield, indicating that seeding rates above 200 000 seeds ha^{-1} are unnecessary. As the plant population increased, plant height, bottom pod height and the number of pods ha^{-1} increased significantly, whilst the number of branches plant^{-1}, pods plant^{-1} and 100-seed mass decreased significantly. AGS 353 and AGS 354 were medium-season cultivars with significantly shorter plant heights, lower bottom pod heights, fewer pods plant^{-1} and lower percentages of export marketable pods, but higher 100-seed masses and seed yields than the long-season cultivars, AGS 352 and Lightning. Lightning had significantly smaller seeds than the other cultivars. AGS 354 yielded significantly better than the other three cultivars and can be recommended for seed and green bean production in areas with a climate similar to Cedara. Due to a significantly high percentage of export marketable pods and a good seed mass, AGS 352 would meet the quality requirements of the international green pod market.

Keywords: Edamame, *Glycine max*, plant population, cultivars

2.2 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill) is a relatively unknown crop in South Africa. It is mainly grown in Japan, Korea, China and Taiwan, as a high-protein crop rich in fat, phosphorus, calcium, iron, vitamin B and B2 (Phany, 1995). In Japan it is referred to as edamame (pronounced *ed-ah-mah-may*), which is translated as “beans on branches”.

Vegetable soybean is larger-seeded, milder-tasting, more tender and more digestible than grain soybean (Born, 2006). The crop is grown mainly for eating like green peas. The pods are harvested at the R6 growth stage while the pods are still bright green and the seeds have developed to fill 80 to 90% of the pod (Diep *et al.*, 2002). The pods are boiled for a few minutes and then the beans are squeezed from the pods and eaten.

The required growing conditions of the crop are similar to those for grain soybean. It is grown in most areas where maize and sugarcane can be grown in KwaZulu-Natal, South Africa (Birch, 2002). Vegetable soybean is grown by small-scale and commercial farmers in South East Asia and therefore could also become an important high-quality food source grown by small-scale, emerging and commercial farmers in South Africa.

Recommendations for suitable plant populations to optimize edamame production are not consistent. Previous research recommended row spacings from 0.15 to 0.75 m with plant populations varying from 43 000 to 430 500 plants ha^{-1}. Sethakoon (1999) obtained significantly higher yields at 266 666 and 400 000 plants ha^{-1} than at 160 000 and 200 000 plants ha^{-1}, but the number of pods $plant^{-1}$ decreased with increased plant population. Kratochvil (2002) reported that 430 000 plants ha^{-1} was too high for acceptable green pod production and that 86 000 plants ha^{-1} produced yields that were too low. Nelson *et al*. (2002) reported that marketable green pod yields increased from 99 000 to 247 000 plants ha^{-1}, but the result was non-significant. Miles and Chen (2000), Feibert *et al.* (2001) and Nelson *et al*. (2002) recommended seeding rate targets of 148 000 to 173 000 seeds ha^{-1}. Edwards *et al*. (2005) and Christmas (2008) recommended higher seeding rates for short-season cultivars.

According to Lee *et al*. (2008), soybean yield is relatively insensitive to plant population with a wide range of seeding rates producing the same yield. However, the optimal seeding rate will vary according to many factors, such as the environmental and climatic conditions under which the crop will be grown, cultivar choice, row spacing and planting date (Edwards *et al*., 2005;

Christmas, 2008; Lee *et al*., 2008; Zhang *et al*., 2010; Liebenberg, 2012). Soybean plants have the ability to adjust their growth habits to account for various spatial distributions and therefore these plant characteristics will respond to various seeding rates in order to contribute to maximum yield (Suhre, 2012). At low plant populations, soybean produces more pods on both the branches and the main stem (Swathi, 2009; Suhre, 2012). Furthermore, less competition for light, water and nutrients occurs among the plants and therefore the plants are better able to produce optimally, especially during periods of stress (Robinson and Conley, 2007).

The objective of this study was to determine the optimum seeding rate of vegetable soybean cultivars with medium and long growing-season lengths.

2.3 MATERIALS AND METHODS

Field trials were planted four times over three seasons from November 2005 to April 2008 at the Cedara Research Centre of the KwaZulu-Natal Department of Agriculture and Rural Development (KZN DARD), South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The mean annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2005 to 2008 was received from an automatic weather station of the Agricultural Research Council: Institute of Soil, Climate and Water (ARC-ISCW) at Cedara. At all the sites the soil was a Hutton form with an orthic A over a red apedal B. Soil analyses showed means of 52% clay and 2.45% organic carbon. The mean pH (KCl) and acid saturation during the experimental period were 4.64% and 2.5% respectively.

2.3.1 Land preparation

Due to the need for crop rotation, a different land was used each season. The lands had been planted to maize in all the preceding seasons. Soil samples were taken from each land during July or August of the same planting year and analyzed by the Fertilizer Advisory Services‟ Laboratories of the KZN DARD based on the Cedara Research Station.

The lands were cultivated twice with a tractor-drawn offset disc-harrow in spring. Prior to planting a tractor–drawn konskilde was used.

2.3.2 Fertilization and planting

Based on the analysis of soil samples, phosphorous (P) was applied as single superphosphate (10.5% P) at a rate of 20 to 45 kg of P ha^{-1} depending on the requirements for each site. The fertilizer was hand-applied to the rows, which were opened using a hand-held V-shaped hoe to a depth of approximately 0.05 m, and thereafter covered with soil. Soil potassium (K) levels were sufficient (above 80 mg K L^{-1}) and therefore no additional K was applied. Nitrogen (N) fertilizer is not recommended for soybean in KwaZulu-Natal, provided the crop is inoculated with bacteria at planting (Birch *et al*., 1990) and therefore no N was applied. All the seed was inoculated with *Bradyrhizobium japonicum* Kirchner at planting using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle applying 250 L ha^{-1} and immediately thereafter covered with 0.02 to 0.03 m of soil using a hand-held rake.

The trials were hand-planted on 17 November 2005, 3 November 2006, 30 October 2007 and 11 December 2007. The first planting in the 2007/08 season experienced a hailstorm on 29 November, which damaged the young plants in the first planting, hence the reason for implementing the second planting in the 2007/08 season. However, the plants in the first planting recovered and the results have been included. Four cultivars, AGS 352 (long-season), AGS 353 (medium-season), AGS 354 (medium-season) and Lightning (long-season) were hand-planted in 0.75 m wide rows at seeding rates of 200 000, 300 000, 400 000 and 500 000 seeds ha^{-1}.

2.3.3 Weed, insect and disease control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[1]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[2]), were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. The post-emergence herbicides bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) and fluazifop-P-butyl (Fusilade Super® EC, 125 g a.i. L^{-1}, Syngenta) were applied five weeks after planting at 1440 and 600 g a.i. ha^{-1}, respectively, with a knapsack sprayer fitted with a Lurmark DT 30 flat spray nozzle applying 250 L ha^{-1}.

[1] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[2] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

The insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[1]), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®; 125/250 g a.i. L^{-1}, Du Pont de Nemours[2]) was applied at 50/100 g a.i. ha^{-1} at early flowering and again three weeks later to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer fitted with a Lurmark DT 30 flat spray nozzle applying 250 L ha^{-1}.

2.3.4 Data collection

Flowering date (R1) was determined when 50% of the plants in the centre two rows had at least one flower. A harvest maturity date (R8) was recorded when 95% of the pods had turned brown.

At harvest maturity the number of plants was recorded in each plot, which consisted of the centre four meters of the two middle rows. Plant height was measured from the ground to the top of the highest pod. Bottom pod height was measured from the ground to the bottom of the lowest seed-bearing pod. Plant height and bottom pod height were only measured in the 2006/07 and 2007/08 seasons. The number of branches $plant^{-1}$ and the number of 1-, 2- and 3-seeded pods were measured on ten randomly selected plants in each plot in both plantings in the 2007/08 season only.

All the plants in the plot were harvested with secateurs soon after maturity, because the pods tended to shatter readily when dry (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007). The plants were then threshed and the grain weighed. The moisture content was determined using a Sinar GrainPro 6310 Moisture Analyzer (Supplier: Ronin Grain Management Solutions, South Africa). The yields were adjusted to 12.5% moisture content.

[1] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.

[2] Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

2.3.5 Statistical analysis

A randomized complete block design with three replicates was used. Each plot consisted of four rows, 5 m in length and spaced 0.75 m apart. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Differences between treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

2.4 RESULTS

2.4.1 Climatic conditions

Total rainfall received and the distribution thereof varied in the three growing-seasons (Table 2.1). Above-average rainfall was received in the 2005/06 season, due to an exceptionally high amount received in January 2006 (246 mm), which coincided with flowering of the medium-season cultivars. However, only 70 mm of rainfall was received in December. Below-average rainfall was received in the 2006/07 season, with January and February being particularly dry. Pod-fill occurred during February and therefore, to ensure a yield, the crop was irrigated with 25 mm on 21 February 2007.

A significant positive correlation was measured between yield and rainfall received in January from 50% flowering (Table 15), indicating the importance of adequate soil moisture during the reproductive stages.

TABLE 2.1 Rainfall recorded at Cedara over the three growing-seasons and the long-term mean

Month	2005/06	2006/07 (mm)	2007/08	Long-term mean*
October	94	111	169	84
November	104	148	166	112
December	70	116	79	127
January	246	75	109	135
February	124	14	75	127
March	84	112	59	110
April	89	34	83	52
Total	**811**	**610**	**740**	**747**

*93 year‟s data (ARC-ISCW, Cedara).

Figures highlighted in green and red indicate months with considerably more or less rainfall than the long-term mean, respectively.

In the 2006/07 season, the mean maximum temperature was higher than the long-term mean and considerably warmer in January and especially February (Table 2.2). In the 2005/06 and 2007/08 seasons the mean maximum temperatures were very similar to the long-term mean. A significant negative correlation was measured between yield and mean maximum temperature (Table 15).

In all three seasons, but especially in the 2005/06 season, the minimum monthly temperatures in January and February were considerably higher than the long-term mean (Table 2.2). Mean minimum temperatures in 2005/06 and 2006/07 seasons were higher than the long-term mean, but this had no significant effect on yield (Table 2.15).

TABLE 2.2 Maximum and minimum monthly temperatures recorded at Cedara for the three growing seasons and the long-term mean

	Maximum temperature				**Minimum temperature**			
Month	**2005/06**	**2006/07**	**2007/08**	**Long-term mean***	**2005/06**	**2006/07**	**2007/08**	**Long-term mean***
				(°C)				
October	24.1	23.8	21.2	22.7	11.7	12.8	11.4	10.8
November	23.9	24.0	23.0	23.6	13.3	13.0	12.8	12.4
December	24.5	25.2	24.5	24.9	12.8	14.9	13.6	13.9
January	25.8	26.9	25.5	25.4	16.5	15.5	15.3	14.9
February	25.7	28.2	26.6	25.4	16.3	15.7	15.0	14.9
March	23.2	25.2	25.1	24.7	13.1	13.9	13.0	13.7
April	22.6	23.6	22.2	22.9	11.3	11.8	9.0	10.6
Mean	**24.3**	**25.3**	**24.0**	**24.2**	**13.6**	**13.9**	**12.9**	**13.0**

*93 year‟s data (ARC-ISCW, Cedara).
Figures highlighted in green and red indicate months with considerably cooler or warmer temperatures than the long-term mean, respectively.

2.4.2 Growth stages

2.4.2.1 Flowering

The planting season did not influence the cultivar and seeding rate interaction for 50% flowering (Table 2.3). It did however, have an effect on the performance of the different cultivars. Overall, the four seeding rates did not affect the time of flowering of the cultivars and no significant interaction between the seeding rate and season was measured. There was a significant reduction in the number of DAP to flowering measured for all the cultivars during the second planting in 2007/08 (Figure 2.1). The long-season cultivars AGS 352 and Lightning had a similar number of DAP to flowering over the four seasons, which was significantly more than cultivars AGS 353 and 354. For the latter two, although there was no significant difference between them, the number of days to flowering increased significantly from 2005/06 to 2007/08.

TABLE 2.3 ANOVA table of the number of days after planting (DAP) to 50% flowering for the cultivars and seeding rates for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	1021.4	**	0.612	-
Cultivar	2801.6	**	0.525	-
Seeding rate	1.00	NS	0.525	-
Season x cultivar	24.11	**	1.055	-
Season x seeding rate	1.00	NS	1.055	-
Cultivar x seeding rate	1.00	NS	1.050	-
Season x cultivar x seeding rate	1.00	NS	2.099	1.9

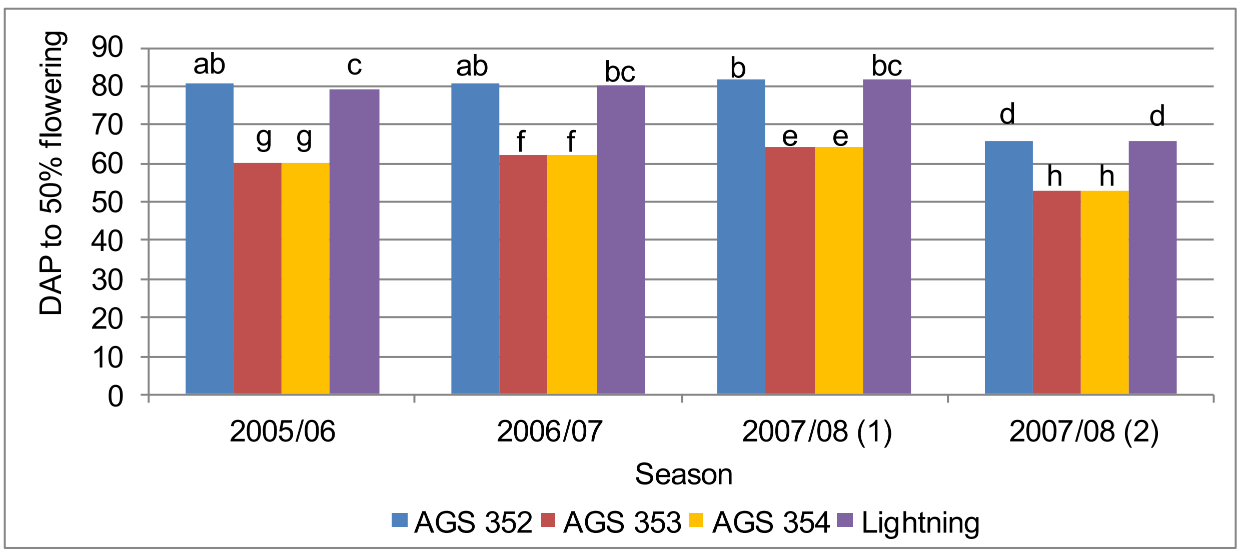

FIGURE 2.1 Number of days (DAP) after planting to 50% flowering of the four cultivars in the four seasons

2.4.2.2 Harvest maturity

As with the number of DAP to 50% flowering, no significant interaction was measured among the seasons, cultivars and seeding rates for the number of DAP to harvest maturity (Table 2.4). However, the seasons did significantly influence the number of DAP to harvest maturity of the four cultivars. The number of DAP to harvest maturity in the second planting in the 2007/08 season was significantly less compared to the other three plantings, whilst in the first planting in the 2007/08 season the number of DAP to harvest maturity was significantly longer than in the other seasons for all the cultivars (Figure 2.2). Cultivars 353 and 354 had similar days to maturity in each planting season, but in the 2006/07 season, there was a significant reduction in the number of DAP to maturity compared to in the 2005/06 and 2007/08 seasons. No significant difference was measured between AGS 352 and Lightning in the 2005/06 season, but in the 2006/07 season, AGS 352 took significantly longer than Lightning to reach maturity, whilst in the 2007/08 (1) season the reverse occurred.

TABLE 2.4 ANOVA table of number of days after planting to harvest maturity for the cultivars and seeding rates for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	6866.9	**	0.679	-
Cultivar	2718.72	**	0.583	-
Seeding rate	1.00	NS	0.583	-
Season x cultivar	107.20	**	1.173	-
Season x seeding rate	1.00	NS	1.173	-
Cultivar x seeding rate	1.00	NS	1.167	-
Season x cultivar x seeding rate	1.00	NS	2.332	1.0

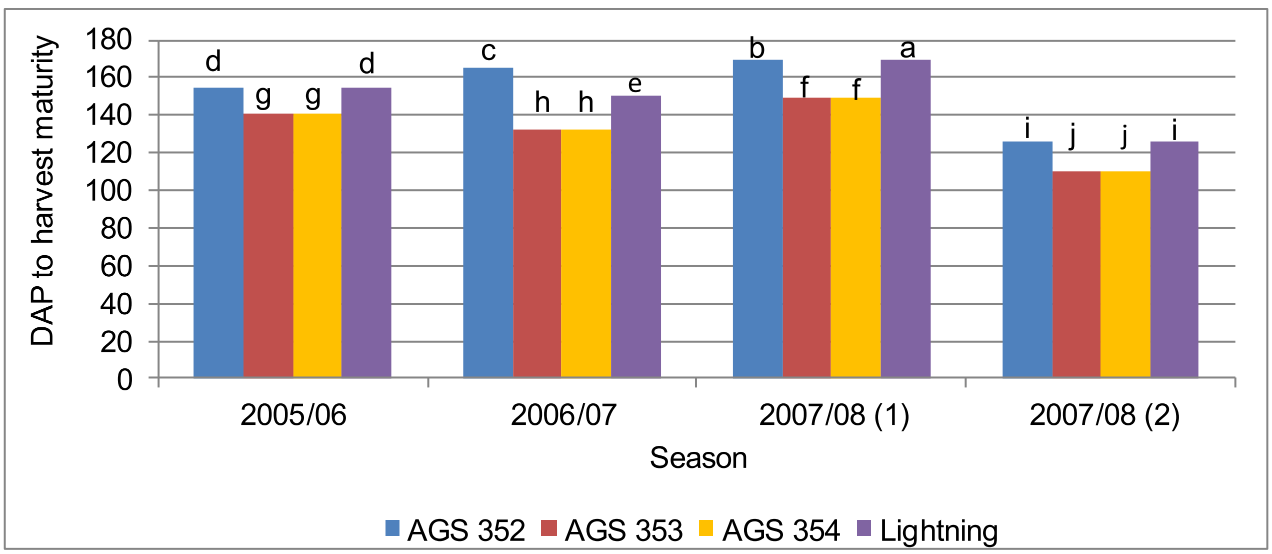

FIGURE 2.2 Number of days after planting (DAP) to harvest maturity of the four cultivars in the four seasons

2.4.3 Plant population

A significant interaction was measured for plant population with the seasons, cultivars and seeding rates (Table 2.5.1). In the 2005/06 season Lightning had significantly lower plant populations at all seeding rates than the other cultivars (Table 2.5.2). No significant differences were measured amongst the other three cultivars at all the seeding rates except at 500 000 plant ha^{-1} where AGS 352 and 353 had significantly higher plant populations than AGS 354. In the 2006/07 season no significant differences were measured among the cultivars at seeding rates from 200 000 to 400 000 seeds ha^{-1}. However, at 500 000 seeds ha^{-1}, Lightning had significantly more plants than AGS 353, but similar plant populations to the other two cultivars. In the 2007/08 (1) season, AGS 353 had significantly fewer plants than the other cultivars at 200 000 and 400 000 seeds ha^{-1}, whilst Lightning had significantly more plants than the other three cultivars at 300 000 and 500 000 seeds ha^{-1}. In the 2007/08 (2) season AGS 353 had significantly more plants than the other cultivars at 300 000 and 500 000 seeds ha^{-1}, whilst at 400 000 seeds ha^{-1} AGS 353 had significantly more plants than AGS 352. Overall, plant population increased significantly with seeding rate. Mean plant population was significantly higher in the 2005/06 and 2006/07 seasons than in the two plantings in the 2007/08 season. The 2007/08 (1) season had a significantly lower mean plant population than the 2007/08 (2) season due to the hailstorm.

Plant population was significantly positively correlated to seeding rate, plant height, bottom pod height and number of pods ha^{-1}, but significantly negatively correlated to seed yield, 100-seed mass, number of branches plant^{-1} and number of pods plant^{-1} (Tables 2.16 to 2.18).

TABLE 2.5.1 ANOVA table of plant population for the cultivars and seeding rates for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	32.37	**	13 623.2	-
Cultivar	1.89	NS	6 887.8	-
Seeding rate	513.30	**	6 887.8	-
Season x cultivar	21.27	**	17 209.0	-
Season x seeding rate	8.11	**	17 209.0	-
Cultivar x seeding rate	1.60	NS	13 775.7	-
Season x cultivar x seeding rate	1.68	*	29 156.0	9.0

TABLE 2.5.2 Plant population for the four cultivars and four seeding rates measured in the four seasons

Season	Cultivar	200 000	300 000	400 000	500 000	Mean
		Seeding rate (plants ha^{-1})				
2005/06	AGS 352	153 889	195 000	245 000	301 111	**223 750**
	AGS 353	140 556	206 667	237 222	316 111	**225 139**
	AGS 354	147 222	205 556	244 444	276 667	**218 472**
	LIGHTNING	119 444	156 111	202 222	242 222	**180 000**
2006/07	AGS 352	117 778	187 778	226 667	281 111	**203 333**
	AGS 353	123 889	180 000	248 333	263 889	**204 028**
	AGS 354	122 222	186 667	240 000	272 778	**205 417**
	LIGHTNING	123 333	167 778	243 333	297 778	**208 056**
2007/08 (1)	AGS 352	125 000	131 667	178 333	176 111	**152 778**
	AGS 353	75 000	125 556	145 556	176 111	**130 556**
	AGS 354	120 000	148 333	183 333	211 111	**165 694**
	LIGHTNING	136 111	183 889	207 222	242 778	**192 500**
2007/08 (2)	AGS 352	104 444	145 556	167 778	221 667	**159 861**
	AGS 353	118 333	202 222	216 111	302 778	**209 861**
	AGS 354	112 778	163 889	188 889	238 333	**175 972**
	LIGHTNING	107 222	163 333	200 556	217 222	**172 083**
	Mean	**121 701**	**171 875**	**210 938**	**252 361**	**189 219**

Figures highlighted in green and red indicate considerably higher or lower plant populations in each season, respectively.

2.4.4 Plant height

No significant interaction was measured for season, cultivar and seeding rate, but a significant interaction was measured for plant height between the seasons and cultivars (Table 2.6). The main effect of seeding rate was also significant. Although plant height generally increased significantly with increasing seeding rate, no significant difference was measured at 300 000 and 400 000 seeds ha^{-1} (Figure 2.3). In the 2006/07 and 2007/08 (1) seasons, the long-season cultivars, AGS 352 and Lightning, had significantly taller plants than the medium-season cultivars, AGS 353 and AGS 354, between which no significant differences were measured (Figure 2.5). The plant height of Lightning was significantly taller than the plant height of AGS 352 in all three seasons. In the 2007/08 (2) season, the plant height of AGS 352 was not significantly different to the plant heights of AGS 353 and AGS 354, but was similar to its plant height in the 2006/07 season. Significantly shorter plants were produced by AGS 352, AGS 353 and AGS 354 in the 2007/08 (1) season than in the other seasons.

Plant height was significantly positively correlated to seeding rate, plant population, bottom pod height, percentage export marketable pods, number of pods plant^{-1} and number of pods ha^{-1}, but significantly negatively correlated to seed yield and 100-seed mass (Tables 2.17 and 2.18).

TABLE 2.6 ANOVA table of plant height for the four cultivars and four seeding rates for three trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	32.82	**	4.01	-
Cultivar	160.35	**	2.08	-
Seeding rate	24.03	**	2.08	-
Season x cultivar	15.59	**	4.71	-
Season x seeding rate	2.09	NS	4.71	-
Cultivar x seeding rate	1.36	NS	4.15	-
Season x cultivar x seeding rate	1.27	NS	7.70	5.6

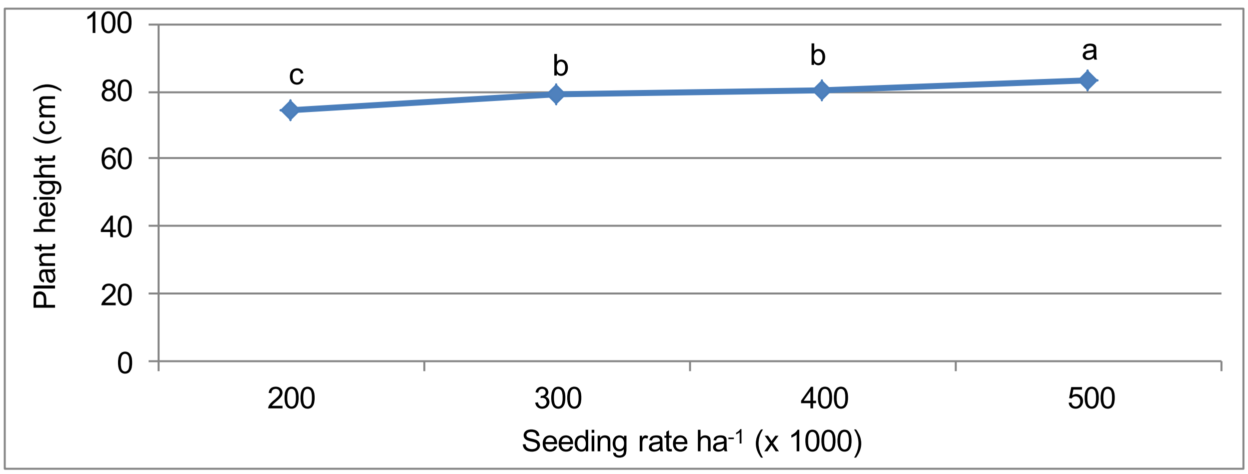

FIGURE 2.3 Mean plant height at the four seeding rates measured over three seasons

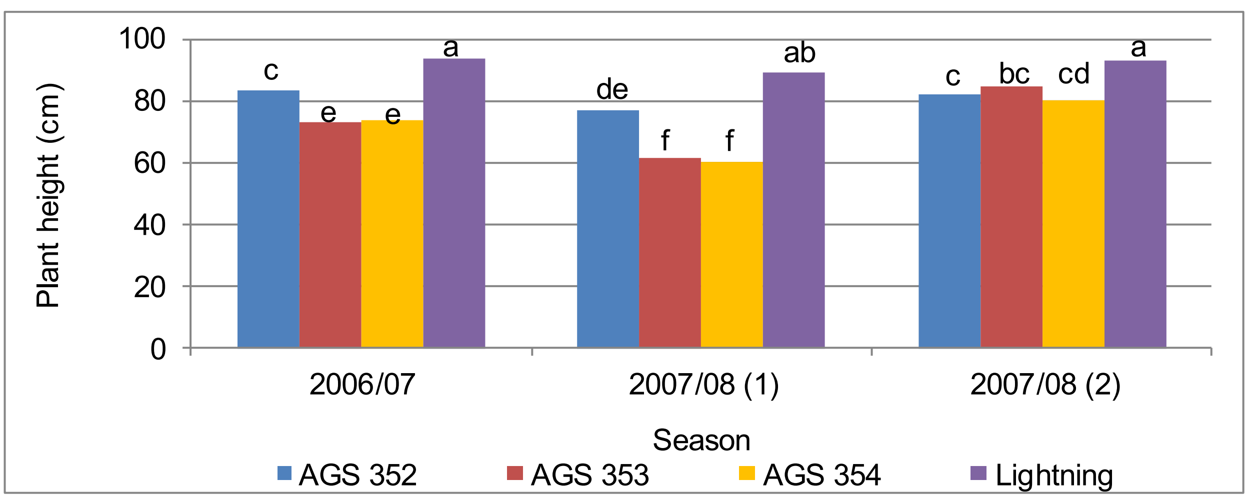

FIGURE 2.4 Plant height of the four cultivars in the three seasons

2.4.5 Bottom pod height

A significant interaction was measured for bottom pod height between the seasons and cultivars, but not with season, cultivar and seeding rate (Table 2.7). Bottom pod height increased significantly only from 200 000 to 300 000 seeds ha^{-1} (Figure 2.6). All the cultivars had significantly lower bottom pod heights in the 2007/08 (1) season than in the 2006/07 season (Figure 2.7). AGS 352 and Lightning had significantly lower bottom pod heights in the 2007/08 (2) season than in the 2006/07 season. The long-season cultivars, AGS 352 and Lightning, had significantly higher bottom pod heights than the medium-season cultivars in the 2006/07 and 2007/08 (1) seasons, but not in the 2007/08 (2) season, where no significant differences were measured among the cultivars.

Bottom pod height was significantly positively correlated to seeding rate, plant population, plant height, percentage export marketable pods and number of pods ha^{-1}, but significantly negatively correlated to seed yield, 100-seed mass and percentage 1-seeded pods (Tables 2.17 and 2.18).

TABLE 2.7 ANOVA table of bottom pod height for the four cultivars and four seeding rates for three trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	29.14	**	2.39	-
Cultivar	29.12	**	1.44	-
Seeding rate	4.58	**	1.44	-
Season x cultivar	4.86	**	2.99	-
Season x seeding rate	0.67	NS	2.99	-
Cultivar x seeding rate	0.70	NS	2.87	-
Season x cultivar x seeding rate	1.30	NS	5.20	15.9

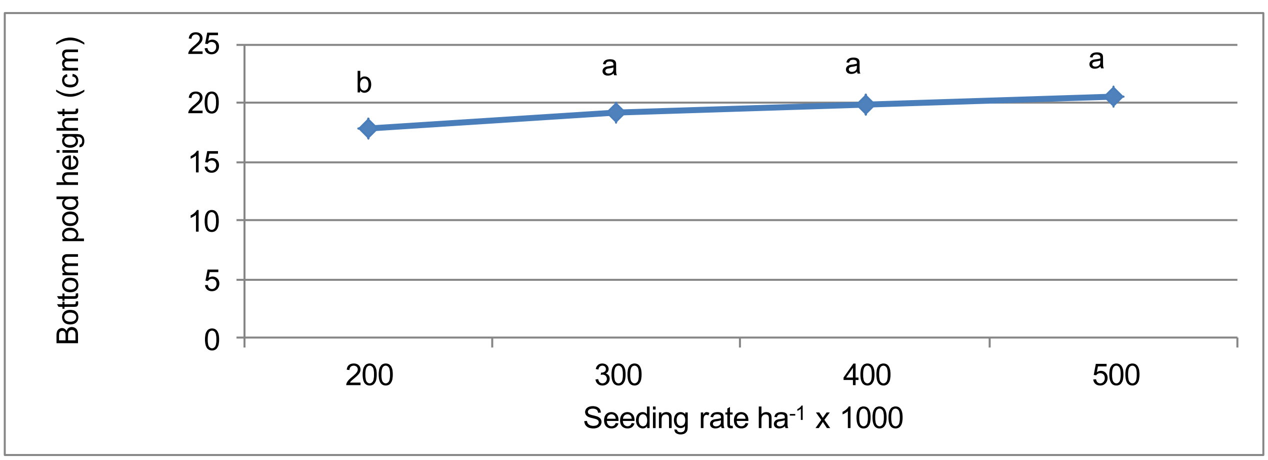

FIGURE 2.5 Mean bottom pod height at the four seeding rates planted over three seasons

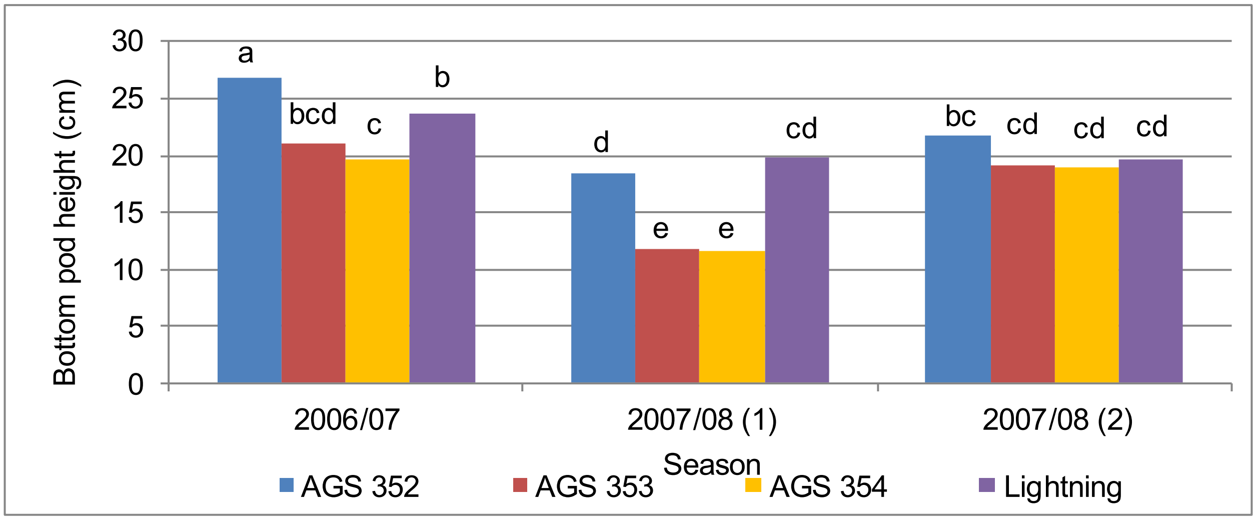

FIGURE 2.6 Bottom pod height of the four cultivars in the three seasons

2.4.6 Number of branches

The number of branches plant^{-1} was only measured in the 2007/08 season. No significant differences in the number of branches plant^{-1} were recorded among the four cultivars and between the two plantings (Table 2.8). However, the number of branches plant^{-1} decreased significantly with increasing seeding rate (Figure 2.7). A significant interaction was measured between the seasons and cultivars. AGS 354 had significantly more branches plant^{-1} in the second planting than in the first planting and the number was significantly higher than those of AGS 352 and Lightning in the second planting (Figure 2.9). No significant differences were measured among the cultivars in the first planting.

A significant interaction was measured for the number of branches plant^{-1} between the seasons and seeding rates (Table 2.8). Only at 200 000 seeds ha^{-1} was a significant difference measured with the number of branches plant^{-1} (Figure 2.9). A significantly higher number of branches plant^{-1} was measured in the first planting than in the second planting.

The number of branches plant^{-1} was significantly positively correlated to percentage 1-seeded pods and the number of pods plant^{-1}, but significantly negatively correlated to seeding rate and plant population (Table 2.18).

TABLE 2.8 ANOVA table of number of branches plant^{-1} for the cultivars and seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	0.03	NS	0.39	-
Cultivar	0.46	NS	0.41	-
Seeding rate	19.85	**	0.41	-
Season x cultivar	2.98	*	0.58	-
Season x seeding rate	2.66	*	0.58	-
Cultivar x seeding rate	1.82	NS	0.81	-
Season x cultivar x seeding rate	1.48	NS	1.14	14.1

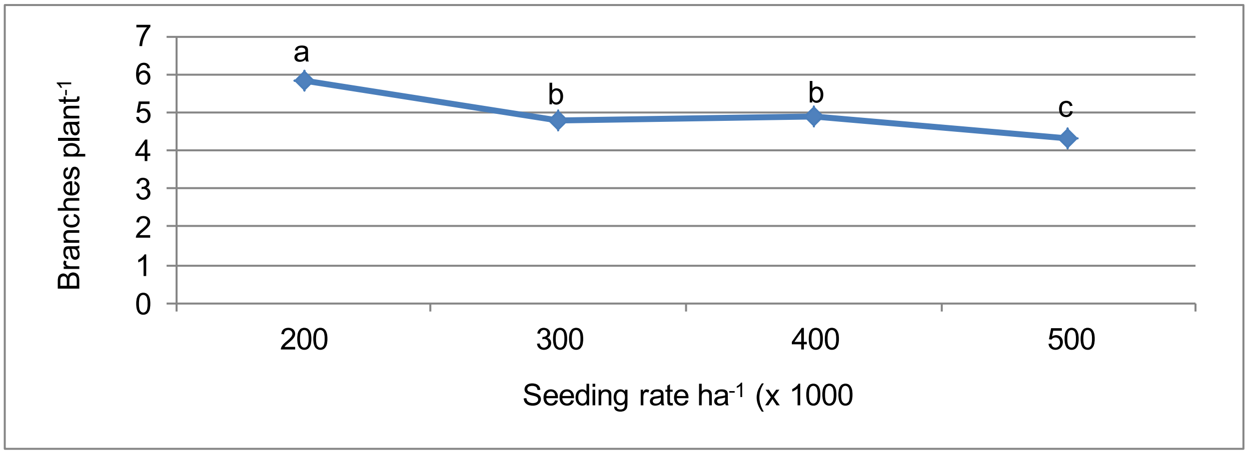

FIGURE 2.7 Mean number of branches plant^{-1} at the four seeding rates over two seasons

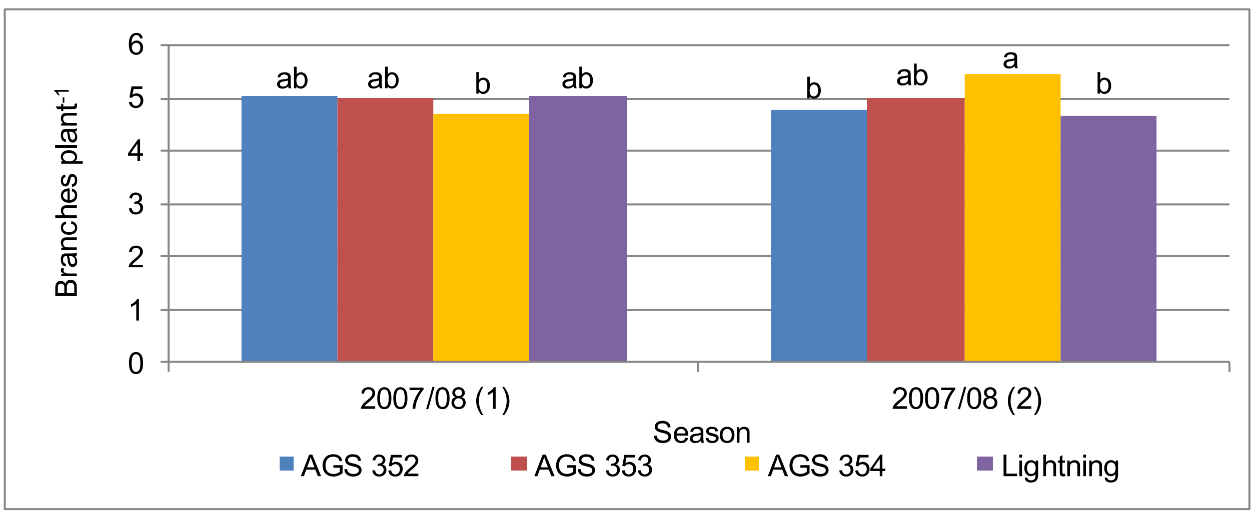

FIGURE 2.8 Number of branches plant^{-1} for the four cultivars in the two seasons

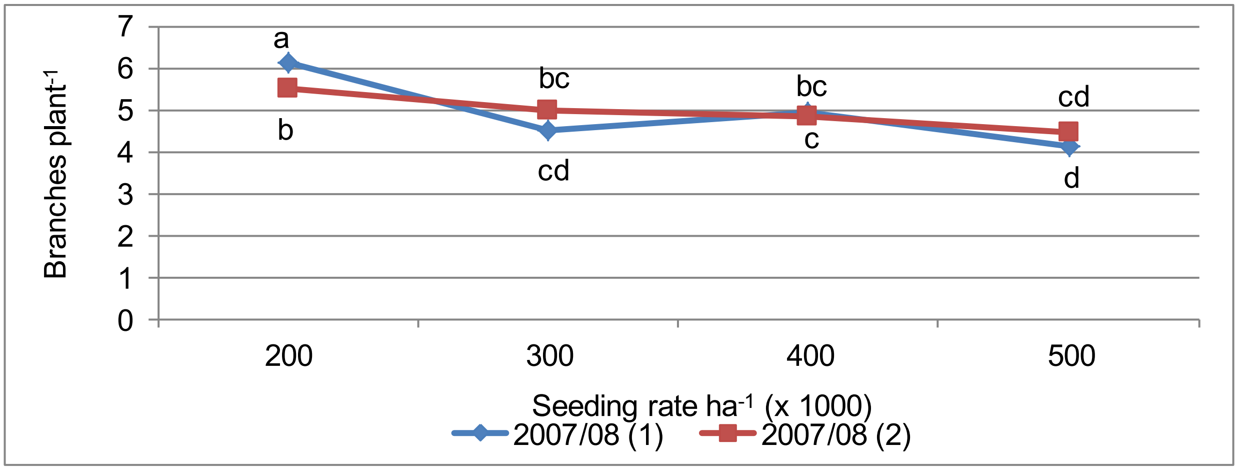

FIGURE 2.9 Response curves of number of branches plant^{-1} at the four seeding rates for the two seasons

2.4.7 Pods and seeds per pod

2.4.7.1 Number of pods plant^{-1}

The number of pods plant^{-1} and seeds pod^{-1} was only recorded in both plantings in the 2007/08 season (Tables 2.9, 2.10 and 2.11). The number of pods plant^{-1} decreased significantly from 200 000 to 300 000 seeds ha^{-1}, but not thereafter, although the number of pods plant^{-1} was lowest at 500 000 seeds ha^{-1} (Figure 2.11). A significant interaction was measured for the number of pods plant^{-1} between the seasons and cultivars (Figure 2.12). AGS 352 and Lightning produced significantly more pods in the first planting, whilst AGS 354 produced significantly more pods in the second planting. Overall, significantly more pods plant^{-1} were produced in the first planting and Lightning produced significantly more pods plant^{-1} than the other cultivars.

The number of pods plant^{-1} was significantly positively correlated to plant height, number of branches plant^{-1}, percentage export marketable pods and the number of pods ha^{-1}, but significantly negatively correlated to seeding rate, plant population and 100-seed mass (Table 2.18).

TABLE 2.9 ANOVA table of number of pods with seeds plant^{-1} for the various cultivars and seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	23.88	**	3.84	-
Cultivar	51.18	**	5.04	-
Seeding rate	14.77	**	5.04	-
Season x cultivar	9.41	**	6.78	-
Season x seeding rate	0.71	NS	6.78	-
Cultivar x seeding rate	0.71	NS	10.08	-
Season x cultivar x seeding rate	0.62	NS	14.06	17.7

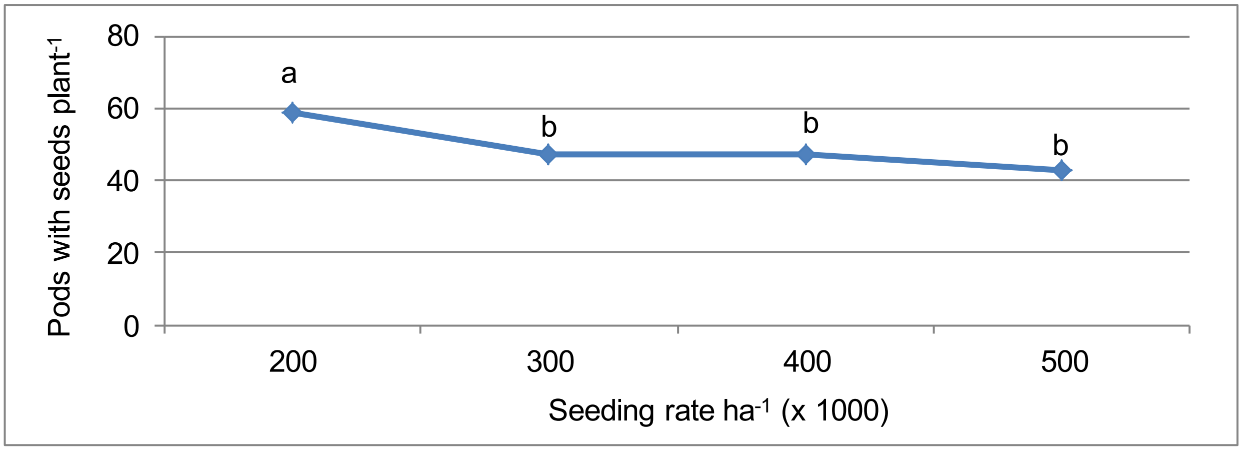

FIGURE 2.10 Mean number of pods plant^{-1} at the four seeding rates over two seasons

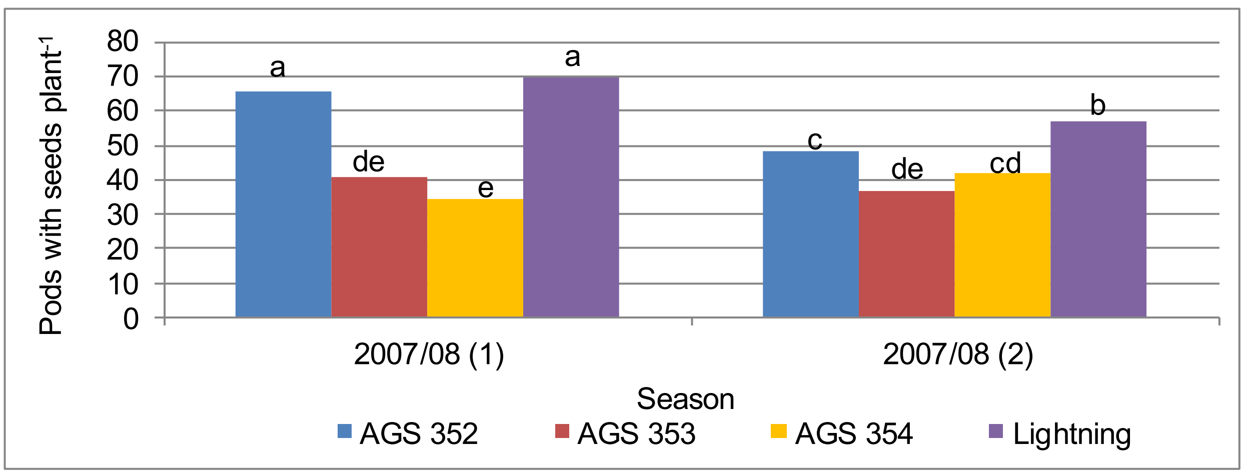

FIGURE 2.11 Number of pods plant^{-1} for the four cultivars in the two seasons

2.4.7.2 One-seeded pods

No significant interactions were measured for percentage 1-seeded pods between the seasons, cultivars and seeding rates (Table 2.10). A significantly higher percentage of 1-seeded pods was produced in the first planting (Figure 2.12). AGS 353 and AGS 354 produced significantly higher percentages of 1-seeded pods than AGS 352 and Lightning (Figure 2.13). Seeding rate had no significant effect on percentage 1-seeded pods.

Percentage 1-seeded pods was significantly positively correlated to seed yield, 100-seed mass and number of branches $plant^{-1}$, but significantly negatively correlated to bottom pod height and percentage export marketable pods (Table 2.18).

TABLE 2.10 ANOVA table of percentage one-seeded pods for the various cultivars at the various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	14.53	*	2.09	-
Cultivar	35.47	**	3.42	-
Seeding rate	2.51	NS	3.42	-
Season x cultivar	1.64	NS	4.45	-
Season x seeding rate	0.42	NS	4.45	-
Cultivar x seeding rate	0.83	NS	6.84	-
Season x cultivar x seeding rate	0.57	NS	9.48	34.7

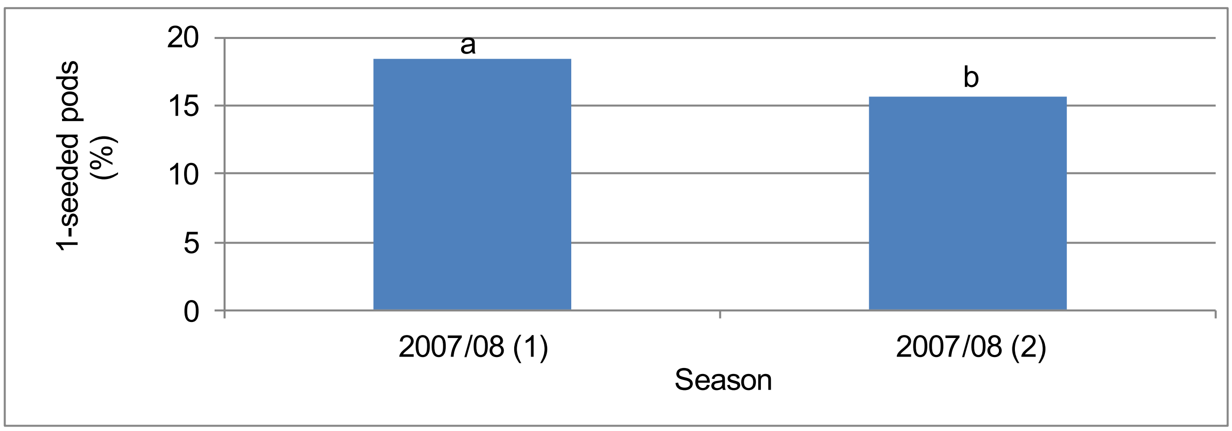

FIGURE 2.12 Percentage one-seeded pods obtained in the two seasons

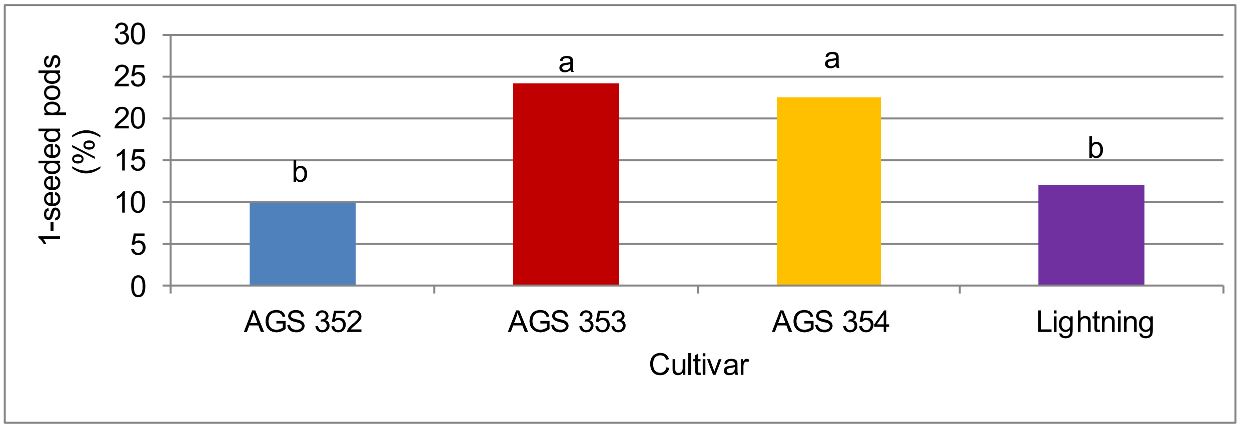

FIGURE 2.13 Percentage 1-seeded pods of the four cultivars over two seasons

2.4.7.3 Export marketable pods*

No significant interactions were measured for percentage export marketable pods between the seasons, cultivars and seeding rates (Table 2.11). Seeding rate had no significant effect on the percentage export marketable pods. However, significant differences were measured among the seasons and cultivars. A significantly lower percentage of export marketable pods was produced in the first planting of 2007/08 (Figure 2.14). AGS 353 and AGS 354 produced significantly lower percentages of export marketable pods than AGS 352 and Lightning (Figure 2.15).

Percentage export marketable pods was significantly positively correlated to plant height, bottom pod height, number of pods plant^{-1} and number of pods ha^{-1}, but significantly negatively correlated to seed yield, 100-seed mass and percentage 1-seeded pods (Table 2.18).

TABLE 2.11 ANOVA table of percentage export marketable pods for the various cultivars at the various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	14.53	*	2.09	-
Cultivar	35.47	**	3.42	-
Seeding rate	2.51	NS	3.42	-
Season x cultivar	1.64	NS	4.45	-
Season x seeding rate	0.42	NS	4.45	-
Cultivar x seeding rate	0.83	NS	6.84	-
Season x cultivar x seeding rate	0.57	NS	9.48	7.1

*Export marketable pods are pods containing two or more beans. The length and width of the pods have not been considered, although they are important charcteristics to meet the requirements of the export market.

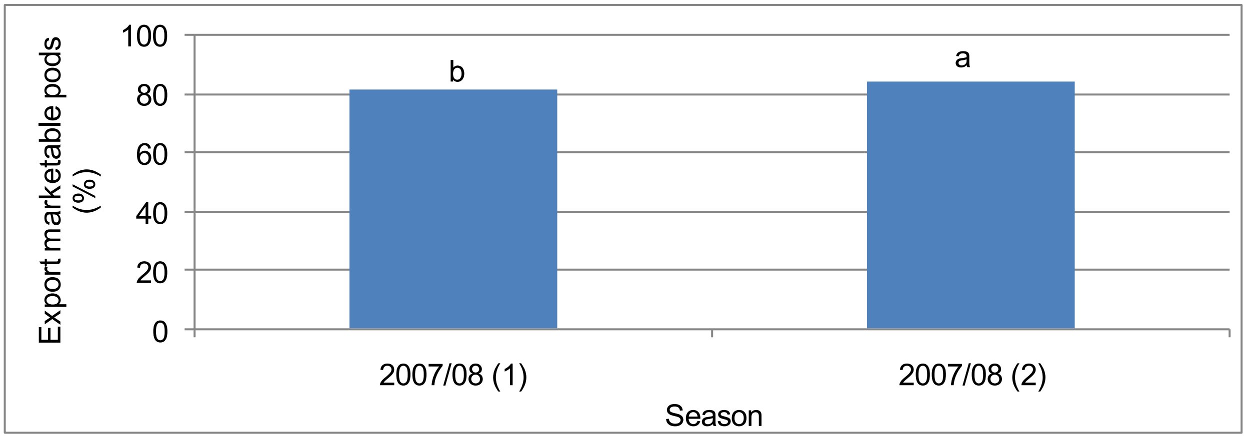

FIGURE 2.14 Percentage export marketable pods obtained in the two seasons

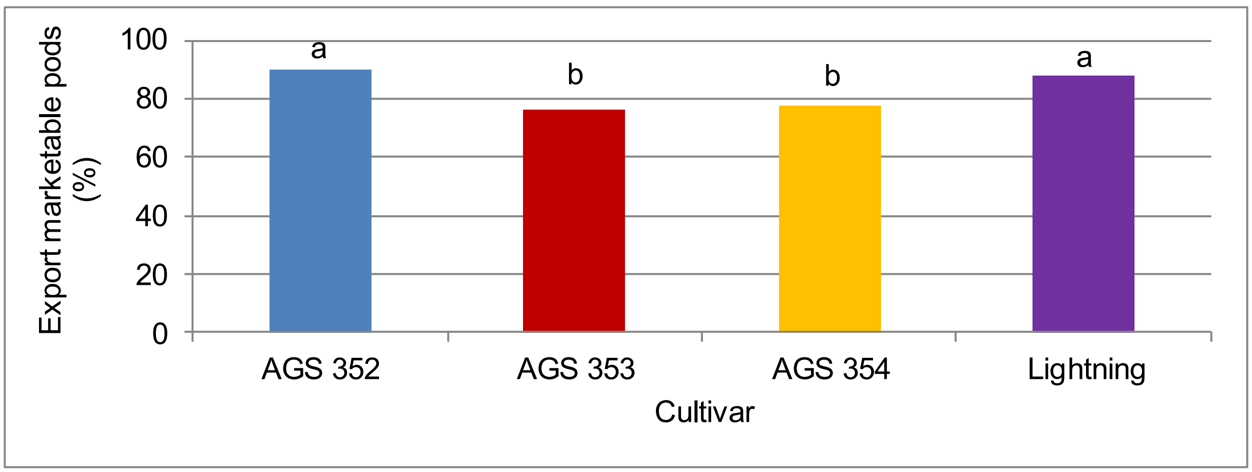

FIGURE 2.15 Percentage export marketable pods for the four cultivars over the two seasons

2.4.7.4 Number of pods ha^{-1}

No significant differences were measured between the seasons for the number of pods produced ha^{-1} (Table 2.12). Significantly more pods ha^{-1} were produced at seeding rates of 400 000 and 500 000 seeds ha^{-1} than at seeding rates of 200 000 and 300 000 seeds ha^{-1} (Figure 2.16). A significant interaction was measured for number of pods ha^{-1} between the seasons and cultivars. The long-season cultivars produced significantly more pods ha^{-1} in the 2007/08 (1) season than in the 2007/08 (2) season, whilst AGS 353 produced significantly more pods ha^{-1} in the 2007/08 (2) season than in the 2007/08 (1) season Figure 2.17). Overall, Lightning produced significantly more pods ha^{-1} than the other cultivars in both seasons.

TABLE 2.12 ANOVA table of number of pods ha^{-1} for the various cultivars at the various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	2.07	NS	1 037 605	-
Cultivar	67.37	**	933 940	-
Seeding rate	17.35	**	833 940	-
Season x cultivar	25.07	**	1 299 071	-
Season x seeding rate	1.49	NS	1 299 071	-
Cultivar x seeding rate	1.49	NS	1 667 880	-
Season x cultivar x seeding rate	1.31	NS	2 400 920	17.8

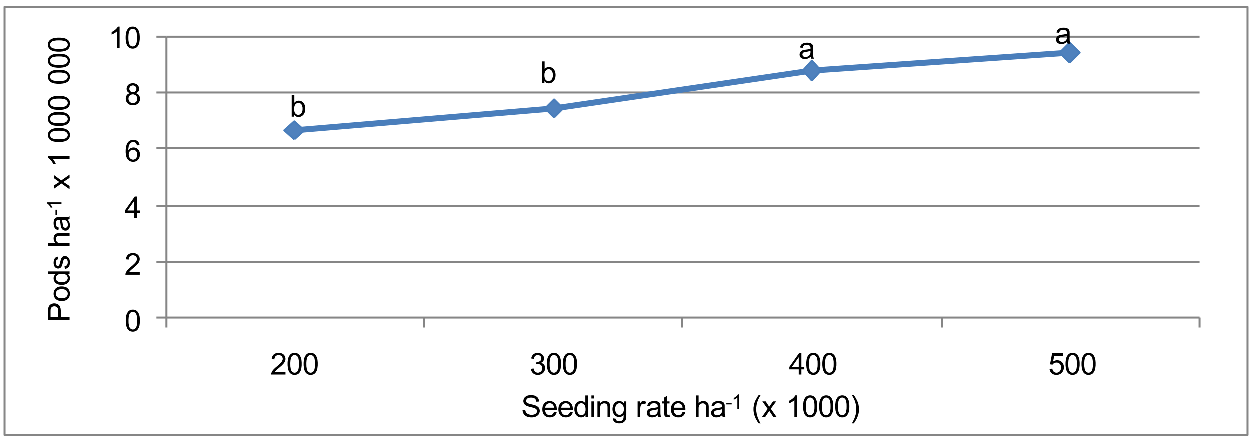

FIGURE 2.16 Mean number of pods ha^{-1} for the four cultivars at the four seeding rates over two season

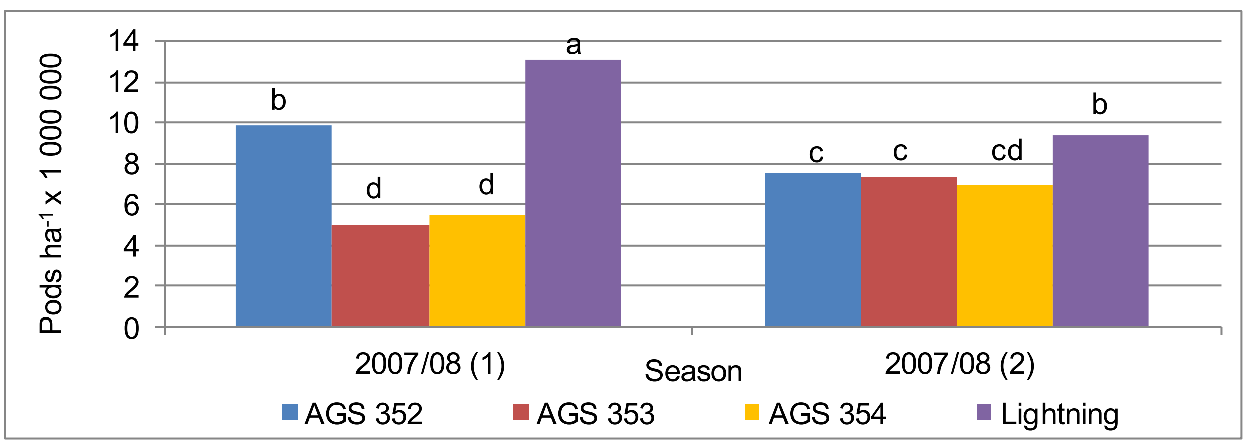

FIGURE 2.17 Number of pods ha^{-1} for the four cultivars in the two seasons

2.4.8 Seed mass

A significant interaction was measured for 100-seed mass between the seasons, cultivars and seeding rates (Table 2.13.1). In all the seasons and at each seeding rate, Lightning had significantly lower 100-seed masses than the other cultivars in all the seasons (Table 2.13.2). In the 2005/06 season AGS 353 and AGS 354 had significantly higher 100-seed masses than AGS 352 at 500 000 seeds ha^{-1}, but not at the lower seeding rates. In the 2006/07 season AGS 352 had significantly higher 100-seed masses at 200 000 and 500 000 seeds ha^{-1} than AGS 353. In the 2007/08 (1) season, AGS 353 and AGS 354 had significantly higher 100-seed masses than AGS 352 at all seeding rates. In the 2007/08 (2) season AGS 353 had a significantly higher 100-seed mass than all the cultivars at 200 000 seeds ha^{-1}, whilst at 300 000 seeds ha^{-1} the 100-seed mass of AGS 353 was only significantly higher than that of AGS 352. At 400 000 and 500 000 seeds ha^{-1} the 100-seed mass of AGS 354 was significantly higher than that of AGS 352. Overall, 100-seed mass decreased significantly with increasing seeding rate and was significantly higher in the 2007/08 (1) season than in the other seasons. AGS 353 and AGS 354 had significantly higher mean 100-seed masses than AGS 352 and Lightning.

100-seed mass was significantly positively correlated to seed yield and percentage 1-seeded pods, but significantly negatively correlated to plant population, plant height, bottom pod height, percentage export marketable pods, number of pods $plant^{-1}$ and number of pods ha^{-1} (Tables 2.16 to 2.18).

TABLE 2.13.1 ANOVA table of 100-seed mass for the various cultivars and various seeding rates for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	102.29	**	1.41	-
Cultivar	356.36	**	1.07	-
Seeding rate	4.89	**	1.07	-
Season x cultivar	13.82	**	2.27	-
Season x seeding rate	1.45	NS	2.27	-
Cultivar x seeding rate	1.31	NS	2.15	-
Season x cultivar x seeding rate	1.65	*	4.35	7.9

TABLE 2.13.2 100-seed mass of the four cultivars at the four seeding rates in the four seasons

Season	Cultivar	Seeding rate ha^{-1} 200 000	300 000	400 000 (g)	500 000	Mean
2005/06	AGS 352	37.7	37.4	33.5	29.7	**34.6**
	AGS 353	37.5	39.6	35.4	36.3	**37.2**
	AGS 354	39.4	39.6	38.3	37.0	**38.6**
	Lightning	19.1	18.7	17.4	16.0	**17.8**
2006/07	AGS 352	36.2	35.6	34.2	36.2	**35.5**
	AGS 353	30.9	35.0	33.1	31.2	**32.6**
	AGS 354	33.9	32.5	35.1	32.7	**33.6**
	Lightning	25.2	21.7	17.6	15.0	**19.9**
2007/08 (1)	AGS 352	37.9	38.1	35.8	39.3	**37.8**
	AGS 353	46.2	45.8	45.4	48.8	**46.5**
	AGS 354	49.0	47.5	46.9	43.6	**46.8**
	Lightning	30.7	30.3	32.0	29.5	**30.6**
2007/08 (2)	AGS 352	31.7	31.0	31.5	32.2	**31.6**
	AGS 353	38.3	35.7	34.4	34.7	**35.8**
	AGS 354	33.4	35.3	37.9	37.2	**36.0**
	Lightning	25.0	24.3	23.8	23.3	**24.1**
	Mean	**34.5**	**34.3**	**33.3**	**32.7**	**33.7**

Figures highlighted in green and red indicate considerably high and low 100-seed masses, respectively.

2.4.9 Seed yield

No significant interaction was measured for seed yield between the seasons, cultivars and seeding rates (Table 2.14). However, a significant interaction was measured for seed yield between the seasons and cultivars. All the cultivars yielded significantly better in the 2007/08 (1) season than in the other seasons (Figure 2.18). AGS 354 produced significantly greater yields in the higher production seasons, 2007/08 (1) and 2005/06, and produced a significantly higher mean yield than AGS 352 and Lightning. Lightning produced the highest yields in the low production seasons, 2006/07 and 2007/08 (2), and the lowest yields in the high production seasons. AGS 352 produced the lowest yields in the lower production seasons. Seeding rate had no significant effect on yield.

Seed yield was significantly positively correlated to 100-seed mass and percentage 1-seeded pods, but significantly negatively correlated to plant population, plant height, bottom pod height and percentage export marketable pods (Tables 2.17 and 2.18).

TABLE 2.14 ANOVA table of seed yield for the various cultivars and various seeding rates for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	38.22	**	198.5	-
Cultivar	8.38	**	114.8	-
Seeding rate	0.77	NS	114.8	-
Season x cultivar	4.31	**	267.4	-
Season x seeding rate	0.75	NS	267.4	-
Cultivar x seeding rate	1.57	NS	229.6	-
Season x cultivar x seeding rate	1.35	NS	476.1	11.0

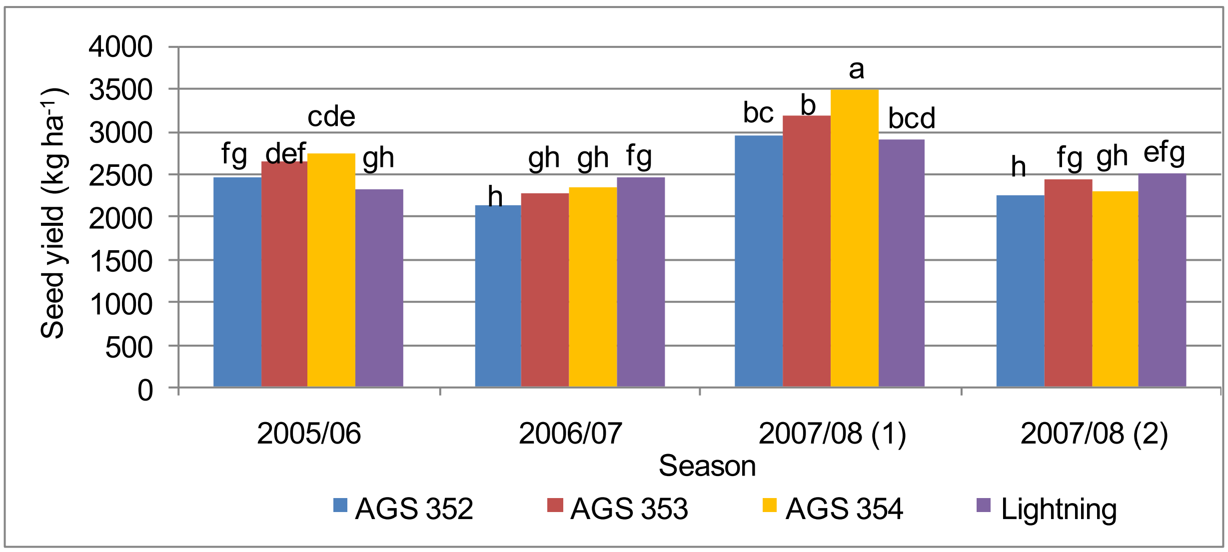

FIGURE 2.18 Seed yield of the four cultivars in the four seasons

2.4.10 Correlations

Correlation coefficients were measured among seed yield, mean maximum and mean minimum temperatures for the seasons and rainfall received in January from 50% flowering (Table 2.15).

TABLE 2.15 Correlation coefficients for seed yield, maximum and minimum temperature and rainfall received in January from 50% flowering

	Seed yield	**Mean maximum temperature**	**Mean minimum temperature**	**Rainfall in January from 50% flowering**
Mean maximum temperature	-0.531 *	---	---	---
Mean minimum temperature	-0.413 NS	0.594 *	---	---
Rainfall in January from 50% flowering	0.561 *	0.073 NS	0.348 NS	---
Rainfall from flowering to harvest	0.361 NS	-0.504 **	0.352 NS	0.523 *

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS = Not significant

Correlations coefficients were measured among the various agronomic characteristics studied in the four seasons (Tables 2.16 to 2.18).

TABLE 2.16 Correlation coefficients for various agronomic characteristics for the 2005/06, 2006/07 and 2007/08 seasons

	Seed yield ha^{-1}	**Plant population**
Plant population ha^{-1}	-0.196 **	---
100-seed mass	0.516 **	-0.184 *

Boxes highlighted in green and red are positively and negatively significant, respectively.

TABLE 2.17 Correlation coefficients for various agronomic characteristics for the 2006/07 and 2007/08 seasons

	Seed yield ha^{-1}	**Plant population ha^{-1}**	**Plant height**	**Bottom pod height**
Plant population ha^{-1}	-0.237 **	---	---	---
Plant height	-0.374 **	0.424 **	---	---
Bottom pod height	-0.557 **	0.400 **	0.594 **	---
100-seed mass	0.539 **	-0.272 **	-0.732 **	-0.563 **

Boxes highlighted in green and red are positively and negatively significant, respectively.

TABLE 2.18 Correlation coefficients for the various agronomic characteristics for the two plantings in the 2007/08 season

	Seed yield ha^{-1}	**Seeding rate ha^{-1}**	**Plant population ha^{-1}**	**Plant height**	**Bottom pod height**	**100-seed mass**	**Branches plant^{-1}**	**% 1-seeded pods**	**% export marketable pods**	**Pods plant^{-1}**
Seeding rate ha^{-1}	-0.034 NS	---								
Plant population ha^{-1}	-0.149 NS	0.767 **	---	---	---	---	---	---	---	---
Plant height	-0.503 **	0.255 *	0.477 **	---	---	---	---	---	---	---
Bottom pod height	-0.562 **	0.129 NS	0.316 **	0.665 **	---	---	---	---	---	---
100-seed mass	0.626 **	-0.018 NS	-0.215 *	-0.816 **	-0.674 **	---	---	---	---	---
Branches plant^{-1}	0.049 NS	-0.524 **	-0.439 **	-0.062 NS	-0.155 NS	0.070 NS	---	---	---	---
% 1-seeded pods	0.345 **	-0.094 NS	0.125 NS	-0.191 NS	-0.343 **	0.337 **	0.296 **	---	---	---
% export marketable pods	-0.345 **	-0.163 NS	-0.125 NS	0.392 **	0.404 **	-0.577 **	0.054 NS	-0.746 **	---	---
Pods plant^{-1}	0.008 NS	-0.318 **	-0.309 **	0.321 **	0.122 NS	-0.416 **	0.350 **	0.130 NS	0.493 **	---
Pods ha^{-1}	-0.109 NS	0.353 **	0.504 **	0.656 **	0.341 **	-0.525 **	-0.040 NS	0.036 NS	0.350 **	0.630 **

Boxes highlighted in green and red are positively and negatively significant, respectively.

NS Not significant

2.5 DISCUSSION

Despite the monthly and seasonal variations in rainfall (Table 2.1), the only significant positive correlation measured between rainfall and yield was when the cultivars flowered in January (Table 2.15). More rain was then received during the reproductive stage and therefore higher yields were obtained. The medium-season cultivars, AGS 353 and AGS 354, flowered in January and overall produced higher yields than the long-season cultivars, AGS 352 and Lightning (Figure 2.19). The significant negative correlation measured between the mean maximum temperature and yield indicated that in the warmer seasons, which were also drier, as in the 2006/07 season, lower yields were produced. Popovic *et al*. (2013) reported that yield was positively correlated to the quantity and distribution of rainfall, but negatively correlated to temperature. Although more favourable growing conditions were experienced during pod-fill in the 2005/06 season, the yield was significantly lower than in the 2007/08 (1) season. The reduced plant population in the 2007/08 (1) season resulted in the production of more pods plant^{-1} and larger 100-seed masses, which significantly increased the mean yield, indicating that high plant populations are unnecessary to achieve good yields.

Studies have shown that water deficits during the vegetative growth stages had little effect on yield, whilst a deficit during the reproductive stages, flowering (R2), pod elongation (R4) and seed enlargement (R6), resulted in significant seed yield reductions (Demirtaş *et al*., 2010). Water deficits during the early reproductive stages, induced flower and pod abortion and reduced the number of pods plant^{-1}. Consequently, the yield loss was greater than when a water deficit occurred during the pod elongation stage (Karam *et al*., 2005; Comlekcioglu and Simsek, 2011). However, a water deficit during pod-fill had the greatest effect on yield reduction (Adeboye *et al*., 2015).

Due to the late planting and warmer temperatures, all the cultivars in the 2007/08 (2) season took significantly fewer numbers of DAP to reach 50% flowering, which occurred in February, and received less rainfall from flowering to harvest, resulting in significantly lower yields than in the 2007/08 (1) season. Swathi (2009) recorded a significant positive correlation between the numbers of DAP to 50% flowering and maturity. This relationship was observed in the trials (Figures 2.1 and 2.2). Cultivar growing-season length is genetically determined, but influenced by temperature (James, 2007; Zhang and Kyei-Bohen, 2007). Beuerlin (2001) and Bekele and Alemahu (2011) reported that soybean seed yield was strongly positively correlated to the number of DAP to maturity, indicating that longer-season cultivars will yield better. However, overall, this did not occur, due to less rainfall being received during the reproductive stages of the long-season cultivars. De Bruin and Pedersen (2007), Zhang *et al.* (2010), Liebenberg (2012) and Sadeghi and Niyaki (2013) reported that sowing date had a significant impact on soybean yield and that the magnitude of the response varied among the cultivars. November is generally the optimum month in which to plant soybean in South Africa, although earlier and later planting dates can be used in the cooler and hotter areas, respectively (Liebenberg, 2012). Due to warmer growing conditions at later planting dates, the number of DAP to flowering is reduced and the growing season is shortened, which consequently results in fewer pods plant^{-1}, lower seed mass and reduced yields (De Bruin and Pedersen, 2007; Sadeghi and Niyaki, 2013). Hence the 2007/08 (2) crop reached 50% flowering and harvest maturity quicker than in the 2007/08 (1) season and consequently produced a lower yield.

At planting the seed beds were sufficiently moist to ensure good germination and emergence. Only 55.4% of the seeds developed into mature plants, despite the use of fresh seed, which had been stored in a cold-room. Interestingly, plant population as a percentage of seeding rate decreased as seeding rate increased. The 2007/08 (1) season had a significantly lower plant population as a result of the damage caused by the hailstorm. The plants were approximately 0.10 m high at the time of the hailstorm. AGS 353 recorded a low plant population in the 2007/08 (1) season. Another batch of AGS 353 seed was used for the 2007/08 (2) season and plant population improved.

Miles and Chen (2000), Hatterman-Valenti *et al.* (2003) and Sánchez *et al.* (2005) reported low seedling emergence and stated that this is a known problem in vegetable soybean production, despite high seed germination rates in laboratory assays. The authors further indicated that poor emergence was not confined to any cultivar or season. Miles and Chen (2000) suspected a soil environment interaction that inhibited seedling emergence. Very wet or cold soil conditions after planting may affect germination and emergence (Herman, 2010), but these conditions were not experienced at Cedara. Sharma (2013) reported that seed fungal infection and soil borne fungi in wet soil resulted in seed and seedling rot, which consequently resulted in poor germination and seedling emergence. The application of a fungicide, such as thiram, to the seed at planting would have improved emergence and plant population (Xue *et al*., 2006). A suitable fungicide applied to the plants during mid-flowering to late pod-fill would have reduced pod and seed infection (Liebenberg, 2012). Hot and humid conditions, which are conducive to *Phomopsis longicolla* Hobbs pod and seed infection, occur in the KwaZulu-Natal Midlands. To ensure good quality seed, it is recommended that the crop be planted late in the season so that harvesting occurs in autumn when the temperatures will be lower, there will be less rain and a lower relative humidity (Chen *et al*., 1991; Khalil, 2001; Yan and Shanmugasundaram, 2001; Khan, 2011; Sharma, 2013).

Hamilton (2007), Zhang and Kyei-Boahen (2007) and Swathi (2009) reported that cultivar growing-season length had a significant positive effect on plant height and bottom pod height. The long-season cultivars had significantly taller plants with higher bottom pod heights than the medium-season cultivars (Figures 2.5 and 2.7). As plant population increased, plant height (Figure 4) and bottom pod height (Figure 2.6) increased significantly, due to increased competition for sunlight among the plants. Christmas (2008) and Epler and Staggenborg (2008) reported a similar relationship. Significant positive correlations were measured among plant population, plant height and bottom pod height (Table 2.16). Similar results were obtained by Sethakoon (1999) and Sharma (2013). The shorter plant heights and lower bottom pod heights obtained in the 2007/08 (1) season were therefore due to the lower plant stand. Bottom pod heights below 0.12 m may result in seed or pod losses if mechanical harvesting is used (Liebenberg, 2012). The medium-season cultivars planted at the lower seeding rates in the 2007/08 (1) season would therefore have incurred seed losses (Figure 2.7).

Soybean plants adjust to low plant populations by producing more branches and pods plant^{-1} (Christmas, 2008; Suhre 2012; Sharma, 2013). The mean number of branches plant^{-1} increased significantly as the seeding rate decreased (Figure 2.8). Taller cultivars tend to produce more branches plant^{-1} (Swathi, 2009). However, no significant differences in the mean number of branches plant^{-1} were recorded among the four cultivars or between the two plantings in the 2007/08 season (Figure 2.9), despite the plants being taller in the second planting.

Swathi (2009) and Sharma (2013) recorded a significant positive correlation between the number of branches plant^{-1} and the number of pods plant^{-1}. Significantly more pods plant^{-1} were produced in the first planting than in the second planting of 2007/08, due, possibly, to the lower mean plant population in the first planting. As seeding rate increased, the number of pods plant^{-1} decreased significantly (Figure 2.11), whilst the number of pods ha^{-1} increased significantly (Figure 2.17). Sharma *et al*. (2013) reported that the number of pods plant^{-1} and pod weight plant^{-1} were higher at lower plant populations. Less total rainfall was received from 50% flowering to harvest in the second planting than in the first planting (Table 2.2) and therefore more flower and/or pod abortion may have occurred and further contributed to the lower number of pods plant^{-1} in the second planting, particularly with the longer-season cultivars (Figure 2.12). Comlekcioglu and Simsek (2011) reported that the number of pods plant^{-1} decreased significantly as the quantity of irrigation water applied to vegetable soybean was reduced.

The long-season cultivars produced significantly more pods plant^{-1} (Figure 2.12). Sharma (2013) measured a significant positive correlation between plant height and the number of pods plant^{-1}, indicating that long-season cultivars produce more pods plant^{-1} than medium-season cultivars. A significant positive correlation was measured between plant height and number of pods plant^{-1} (Table 2.17).

Despite receiving less rainfall from 50% flowering to harvest, the long-season cultivars produced significantly higher percentages of export marketable pods than the medium-season cultivars (Figure 2.16) and a significantly higher mean percentage of export marketable pods was obtained in the 2007/08 (2) season than in the 2007/08 (1) season (Figure 2.15). Significantly higher percentages of export marketable pods were produced at 200 000 and 300 000 seeds ha^{-1} than at 500 000 seeds ha^{-1} (Figure 2.18). Sharma (2013) reported a higher percentage of two-seeded pods at a plant population of 160 000 plants ha^{-1} than at a population of 220 000 plants ha^{-1}. To meet the quality requirements for the Asian market, at least two beans pod^{-1} are required (Miles and Zenz, 1996) and therefore lower seeding rates will be more beneficial. However, pods with only one bean can be shelled and marketed as green beans.

Percentage export marketable pods was significantly negatively correlated to 100-seed mass (Table 2.18), because the longer-season cultivars and the 2007/08 (2) season had lower 100-seed masses (Table 2.12.2). As plant population increased, 100-seed mass decreased significantly. Therefore, the higher 100-seed masses recorded in the 2007/08 (1) season were as a result of the significantly lower mean plant population in that season (Table 2.5.2). As seed size is a key quality requirement of edamame, low plant populations would therefore be advised, especially for small-seeded cultivars such as Lightning, which only met this requirement at seeding rates from 200 000 to 400 000 seeds ha^{-1} in the 2007/08 (1) season. The minimum export quality requirement is 30 g per 100 dry seeds (Lal *et al.*, 2001). James (2007) reported that 100-seed mass decreased linearly as plant population increased from 50 000 to 400 000 plants ha^{-1}. However, the author found no differences in seed size for the cultivars, Bunya and C784, at plant populations ha^{-1} from 200 000 to 400 000 and from 50 000 to 200 000, respectively. Epler and Staggenborg (2008) reported that seed mass significantly influenced grain yield.

According to Lee *et al.* (2008), soybean yield is relatively insensitive to plant population with a wide range of seeding rates producing the same yield. Soybean has the ability to adjust its growth habit to account for various spatial distributions and therefore these plant characteristics will respond to various seeding rates in order to contribute to maximum yield (Suhre, 2012). Due to the poor emergence overall, the plant populations obtained in this trial ranged from 120 000 to 250 000 plants ha^{-1}. Seeding rate had no significant effect on yield, whilst plant population was significantly negatively correlated to yield, even at these low plant populations (Table 2.17). Nelson *et al*. (2002) reported no significant differences in green pod yield at plant populations from 100 000 to 250 000 plants ha^{-1}. Sharma (2013) obtained more pods $plant^{-1}$ and higher pod yields $plant^{-1}$ at lower plant populations, but lower yields per unit area. Epler and Staggenborg (2008), Bekele and Alemahu (2011), Comlekcioglu and Simsek (2011), Sarutayophat (2012) and Sharma (2013) reported that soybean seed yield was strongly correlated to the number of seeds $plant^{-1}$, pods $plant^{-1}$ and seeds pod^{-1}.

The plants compensated for decreasing plant populations by producing more branches $plant^{-1}$, pods $plant^{-1}$ and seeds pod^{-1} and higher 100-seed masses. Therefore, seeding rates above 200 000 seeds ha^{-1} are unnecessary to maximize edamame production with the cultivars evaluated and the quality requirements will be ensured. However, Lee *et al*. (2008) and Zhang *et al*. (2010) recommended higher seeding rates with late planting dates, because the number of pods $plant^{-1}$ and yield decline, due to a shorter pod-fill period resulting from warmer temperatures. Higher seeding rates may be required for cultivars with shorter growing-seasons than those evaluated (Edwards *et al*., 2005; Christmas, 2008), but not at late planting dates, because they appear to be more stable (Egli and Bruening, 2002; Christmas, 2008 and Zhang *et al*., 2010). A narrower inter-row spacing may increase yield (De Bruin and Pedersen, 2007; Liebenberg, 2012), because early canopying of the crop will reduce moisture loss through epavoration and suppress weed growth.

Lower seed costs will be incurred at reduced seeding rates, thereby making the crop more profitable. De Bruin and Pedersen (2007) reported that no difference in economic return was obtained with grain soybean at seeding rates from 185 000 to 556 000 seeds ha^{-1} due the cost of the seed.

The high yield obtained with the low plant population in the 2007/08 (1) season suggested that seeding rates below 200 000 seeds ha^{-1} may result in high yields. AGS 354 produced high yields and would therefore be best suited for green bean production, whilst AGS 352 may be most suitable for green pod production due to its production of a high percentage of export marketable pods.

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CHAPTER 3

THE EFFECT OF SEEDING RATE ON THE PRODUCTION OF VEGETABLE SOYBEAN CULTIVARS WITH VARYING GROWING-SEASON LENGTHS

3.1 ABSTRACT

Vegetable soybean (*Glycine max* (L.) Merrill), also known as edamame, is poorly known in South Africa, but this high-protein crop could be suitable for both small-scale and commercial production. The seeds are larger, milder-tasting and more tender than grain soybeans. The pods are picked green when the beans have filled 80 to 90% of the pod. The beans are usually eaten like green peas. Trials were conducted at the Cedara Research Station, KwaZulu-Natal, South Africa in the 2012/13 and 2013/14 seasons to determine the optimum seeding rate for vegetable soybean cultivars with varying growing-season lengths at seeding rates of 50 000 to 250 000 seeds ha^{-1}. The cultivars evaluated in both seasons were AGS 353 and AGS 354 (medium growing-season) and Lightning (long growing-season). AGS 292 (short growing-season) was only evaluated in the 2013/14 season. Seeding rate and plant population had no significant effect on the seed yield of AGS 353 (3.47 t ha^{-1}), AGS 354 (3.28 t ha^{-1}) and Lightning (3.42 t ha^{-1}) in both seasons, but yield differences among the cultivars and seasons were related to the quantity of rainfall received from 50% flowering to harvest maturity. AGS 292 produced significantly higher yields from 150 000 to 250 000 seeds ha^{-1} than from 50 000 to 100 000 seeds ha^{-1}. AGS 292 had significantly shorter plants, which did not canopy in the 0.75 m wide rows. This resulted in weed competition and consequently, a significantly lower yield (1.94 t ha^{-1}) than the other cultivars. The number of branches plant^{-1} and pods plant^{-1} decreased significantly, whilst plant height, bottom pod height, percentage one-seeded pods and the number of pods per hectare increased significantly, with increasing seeding rate. As cultivar growing-season length increased, plant height, bottom pod height, number of pods plant^{-1} and number of pods ha^{-1} increased. Lightning had a significantly lower 100-seed mass than the other cultivars. Seeding rates of 50 000, 75 000 and 150 000 seeds ha^{-1} appeared optimal for Lightning, AGS 353 and AGS 354, respectively. Further research with AGS 292 is required to determine the optimum combination of seeding rate and row spacing for this short-season cultivar.

Keywords: Edamame, seeding rate, cultivars

3.2 INTRODUCTION

The implementation of various management practices is essential for the economic production of vegetable soybean (edamame) to be maximised economically. Establishment of the crop at the optimum seeding rate is an important factor because it will have a strong influence on the yield and marketability of the crop. When marketed, the fresh green pods should contain two or more beans. When sold as whole plants, the plants should carry as many pods as possible (Born, 2006). The cost of edamame seed in South Africa is expected to be higher than that of grain soybean. This input cost will therefore have an effect on the profitability of the crop.

Recommendations for suitable seeding rates to optimize edamame production are not consistent. According to Lee *et al*. (2008), yields of grain soybean are relatively insensitive to plant population, with a wide range of seeding rates producing the same yield. However, the optimal seeding rate varies according to many factors, such as the environmental and climatic conditions under which the crop is grown, cultivar choice, row spacing and planting date (Edwards *et al*., 2005; Christmas, 2008; Lee *et al*., 2008; Zhang *et al*., 2010; Liebenberg, 2012). Soybean plants have the ability to adjust their growth habits to account for various spatial distributions and therefore these plant characteristics will respond to various seeding rates in order to contribute to maximum yield (Suhre, 2012). At low plant populations, soybean produces more pods on both the branches and the main stem (Christmas, 2008; Epler and Staggenborg, 2008; Swathi, 2009; Liebenberg, 2012; Suhre, 2012). Furthermore, less competition for light, water and nutrients occurs among the plants and therefore the plants are better able to produce optimally, especially during periods of stress (Robinson and Conley, 2007).

Plant components that influence soybean yield are plant height, number of nodes plant^{-1}, number of pods node^{-1}, number of seeds pod^{-1} and seed size (Liu *et al*., 2010). Bekele and Alemahu (2011) reported that soybean seed yield was strongly correlated to the number of seeds plant^{-1}, pods plant^{-1}, seeds pod^{-1} and the number of days to maturity, whilst Epler and Staggenborg (2008) reported that seed mass influenced grain yield considerably. Swathi (2007) measured a negative correlation between growing-season length and seed mass. Although seed mass is genetically determined, it is affected by the growing conditions (Duppong and Hatterman-Valenti, 2005; Carson *et al*., 2011). James (2007) reported that seed mass decreased linearly as plant population increased from 50 000 to 400 000 plants ha^{-1}.

Cultivar growing-season length, which is genetically determined, will affect yield. As cultivar growing-season length increases, the plants become taller and produce more pods, thus achieving higher yields (Zhang and Kyei-Boahen, 2007). For short-season cultivars to yield as much as long-season cultivars, higher seeding rates in closer rows are recommended (Edwards *et al*., 2005; Christmas, 2008). Higher seeding rates may also be required for late plantings, because pod number and yield decline as a result of warmer conditions, which shorten the growing period (Zhang *et al*., 2010).

Seeding rates used by researchers have ranged from 43 000 to 500 000 seeds ha^{-1}. In four trials conducted at the Cedara Research Station, KwaZulu-Natal, South Africa, no significant differences in the yield of four vegetable soybean cultivars were measured at seeding rates from 200 000 to 500 000 seeds ha^{-1}. The yields were highest at 200 000 seeds ha^{-1}, indicating that high seeding rates were unnecessary for optimum production. The plants compensated for low populations by producing more branches $plant^{-1}$, pods $plant^{-1}$ and larger seeds.

Hamilton (2007) recommended seeding rates from 148 000 to 173 000 seeds ha^{-1} for edamame production, whilst Birch (2002) recommended a seeding rate of 100 000 seeds ha^{-1} for KwaZulu-Natal.

The objective of this study was to determine the optimum seeding rate of vegetable soybean cultivars with varying growing-season lengths grown under dryland conditions at Cedara.

3.3 MATERIALS AND METHODS

A field experiment was conducted in the 2012/13 and 2013/14 seasons at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m) of the KwaZulu-Natal Department of Agriculture and Rural Development (KZN DARD), South Africa. The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2012/13 and 2013/14 seasons was received from the automatic weather station of the Agricultural Research Council – Institute of Soil, Climate and Water (ARC-ISCW) on the Cedara Research Station. The soil was a Hutton form with an orthic A over a red apedal B.

3.3.1 Land preparation

Due to the need for crop rotation, different lands were used each season. The lands had been planted to maize in the preceding seasons. Soil samples were taken from each land during July or August of the same planting year and analyzed by the Fertilizer Advisory Services" Laboratories of the KZN DARD based on the Cedara Research Station.

The lands were cultivated twice with a tractor-drawn offset disc harrow in spring. Prior to planting a tractor–drawn konskilde was used.

3.3.2 Fertilization and planting

Soil analysis of the 2012/13 trial site showed 48% clay, 3.2% organic carbon, 4.49% pH (KCl) and 4% acid saturation. Soil analysis of the 2013/14 trial site showed 47% clay, 3.6% organic carbon, 5.06% pH (KCl) and 1% acid saturation. Based on the analysis of the soil samples, 20 kg ha^{-1} phosphorous, supplied as single superphosphate (10.5% P), was hand-applied in both seasons to the rows, which were opened using a hand-held V-shaped hoe to a depth of approximately 0.05 m. No additional nutrients were applied. The fertilizer was then covered with a 0.02 to 0.03 m deep layer of soil.

The experiments were hand-planted on 6 November 2012 and 12 November 2013. In both experiments three cultivars, AGS 353, AGS 354 and Lightning were hand-planted at six seeding rates, namely 50 000, 75 000, 100 000, 150 000, 200 000 and 250 000 seeds ha^{-1}. In the 2013/14 season a short-season cultivar, AGS 292, was included in the trial. All the seed was coated with a fungicide, thiram, prior to planting in the 2012/13 season only. No fungicide was applied in the 2013/14 season. A seed inoculant, *Bradyrhizobium japonicum* Kirchner, was mixed in water in a 16 litre knapsack fitted with a Lurmark DT 30 flat spray nozzle and sprayed onto the seed at a rate of 250 L ha^{-1} after it had been placed in the row. Immediately thereafter the seed was covered with soil using a hand-held rake.

3.3.3 Weed, insect and disease control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[1]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[2]) were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. The post-emergence herbicides bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) and fluazifop-P-butyl (Fusilade Super® EC, 125 g a.i. L^{-1}, Syngenta) were applied five weeks after planting at 1440 and 600 g a.i. ha^{-1}, respectively, with a knap-sack sprayer fitted with a Lurmark DT 30 flat spray nozzle.

The insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[3]), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®; 125/250 g a.i. L^{-1}, Du Pont de Nemours[4]) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle.

3.3.4 Data collection

Flowering date (R1) was determined when 50% of the plants in the centre two rows had at least one flower. A harvest maturity date (R8) was recorded when 95% of the pods had turned brown.

At harvest maturity the number of plants was recorded in each plot, which consisted of the centre four meters of the two middle rows. Plant height, which was measured from the ground to the top of the highest pod, bottom pod height, which was measured from the ground to the bottom of the lowest pod, the number of branches $plant^{-1}$ and the number of 1-, 2- and 3-seeded pods were measured on ten randomly selected plants in each plot.

[1] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[2] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

[3] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.

[4] Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

All the plants in the plot were harvested with secateurs soon after maturity, because the pods tended to shatter readily when dry (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007). The plants were then threshed and the grain was weighed. The moisture content was determined using a Sinar GrainPro 6310 Moisture Analyzer (Supplier: Ronin Grain Management Solutions, Modderfontein, South Africa). The yields were adjusted to 12.5% moisture content.

3.3.5 Statistical analysis

A randomized complete block design with three replicates was used. Each plot consisted of four rows, 5 m in length and spaced 0.75 m apart. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

Due to the inclusion of AGS 292 in the 2013/14 season, the data from the two seasons have been analysed separately, except for yield with the cultivars AGS 353, AGS 354 and Lightning.

3.4 RESULTS

3.4.1 Climatic conditions

The total rainfall received in the 2012/13 growing-season was almost similar to the 93 year long-term mean and was more evenly distributed than in the 2013/14 season, which received more rain due to 240 mm falling in March 2014 (Table 3.1). Considerably warmer maximum temperatures were recorded in both seasons than the long-term mean, especially during January and February (Table 3.2). The high rainfall received in March 2014 occurred during grain-fill and resulted in a higher mean yield in the 2013/14 season than in the 2012/13 season for the three cultivars, AGS 353, AGS 354 and Lightning (Table 3.3). Lightning produced a higher yield than AGS 353 and AGS 354 in the 2013/14 season, due to cooler conditions and higher rainfall during pod-fill (R5). The yields obtained in the 2013/14 season improved as the quantity of rainfall received per day increased from 50% flowering to harvest maturity.

TABLE 3.1 Rainfall recorded at Cedara over the two growing-seasons

Month	2012/13	2013/14 (mm)	Long-term mean*
November	106	105	112
December	121	138	130
January	123	98	135
February	131	96	121
March	73	240	110
April	109	17	51
Total	**663**	**694**	**659**

* 93 years" data (Source: ARC-ISCW). The figures highlighted in red and green indicate months with very low and high rainfall, respectively, when compared to the long-term mean.

TABLE 3.2 Mean maximum and minimum monthly temperatures recorded at Cedara in the two growing-seasons

	Maximum temperature			Minimum temperature		
Month	2012/13	2013/14	Long-term mean (°C)	2012/13	2013/14	Long-term mean
November	22.7	25.5	23.6	12.3	12.5	12.4
December	26.3	24.0	24.9	14.9	13.6	13.9
January	26.7	27.7	25.4	15.3	15.6	14.9
February	27.2	28.2	25.4	14.8	15.7	14.9
March	25.0	26.3	24.7	14.0	14.0	13.7
April	23.7	24.1	22.9	9.6	9.3	10.6
Mean	**25.3**	**26.0**	**24.5**	**13.5**	**13.5**	**13.4**

* 93 years" data (Source: ARC-ISCW). The figures highlighted in red indicate when the monthly mean maximum temperatures were considerably higher than the long-term mean.

TABLE 3.3 Rainfall received for the various cultivars from 50% flowering to harvest maturity for the various months and yield obtained in the two seasons

Season	Month	Cultivar AGS 292	AGS 353	AGS 354	Lightning
		(mm)			
2012/13	January	-	83	83	-
	February	-	131	131	131
	March	-	50	50	73
	April	-	-	-	38
	Total rainfall	**-**	**264**	**264**	**242**
	Rainfall day^{-1}	**-**	**3.62**	**3.62**	**3.14**
	Yield (kg ha^{-1})	**-**	**3 195**	**3 036**	**3 653**
2013/14	January	98	58	58	-
	February	96	96	96	94
	March	75	239	239	240
	April	-	-	-	1
	Total rainfall	**269**	**393**	**393**	**335**
	Rainfall day^{-1}	**4.26**	**5.54**	**5.46**	**5.15**
	Yield (kg ha^{-1})	**1 939**	**3 743**	**3 515**	**3 177**

3.4.2 Growth stages

The number of days after planting to 50% flowering and harvest maturity varied with the cultivars and seasons (Figures 3.1 and 3.2). AGS 292 had the shortest growing-season taking 52 DAP to reach 50% flowering and 115 DAP to reach harvest maturity. Lightning had the longest growing-season taking 81 and 84 DAP to reach 50% flowering and 158 and 149 DAP to reach harvest maturity in the 2012/13 and 2013/14 seasons, respectively. AGS 353 and AGS 354 had similar DAP to reach the two growth stages, but took longer to reach 50% flowering in the 2013/14 season, despite the warmer growing conditions.

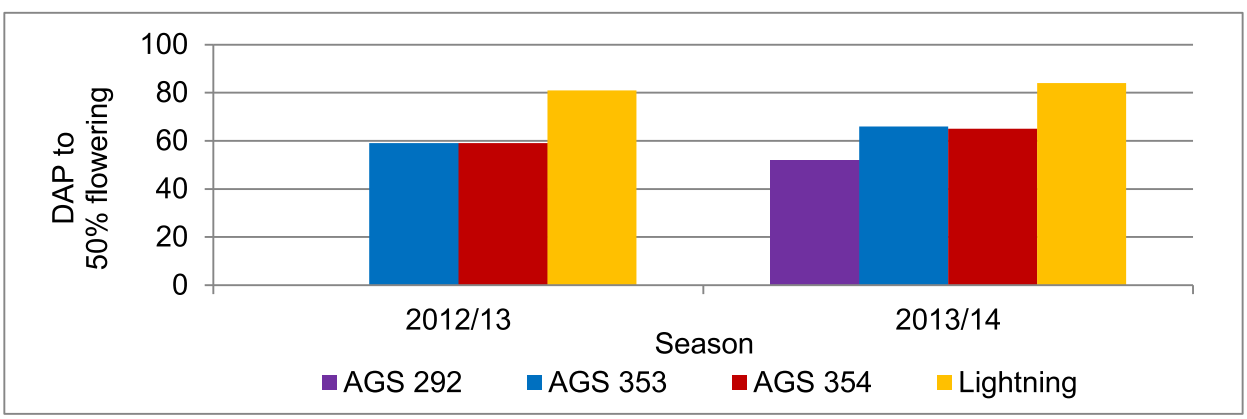

FIGURE 3.1 Number of days after planting to 50% flowering for the cultivars in the two seasons

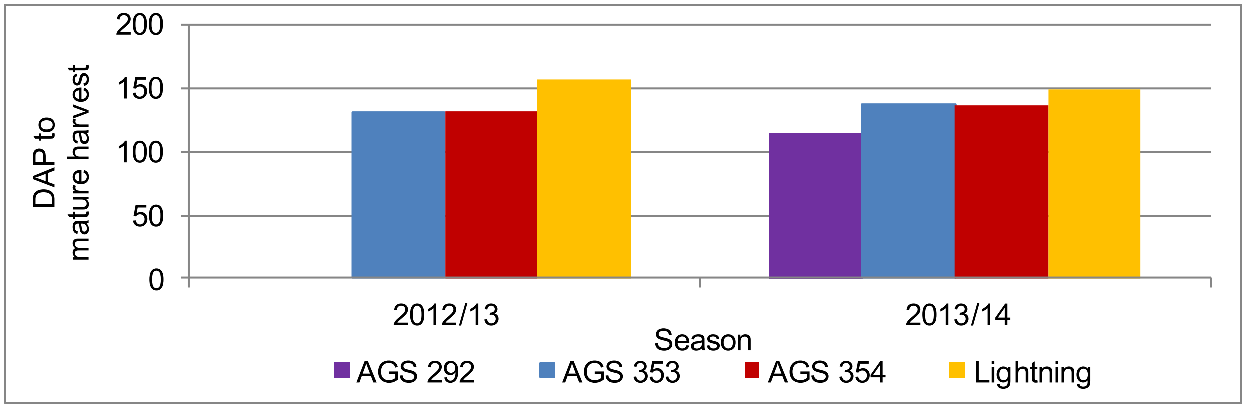

FIGURE 3.2 Number of days after planting to maturity for the cultivars in the two seasons

3.4.3 Plant population

Mean plant population as a percentage of seeding rate was 87.3% and 68.2% in the 2012/13 and 2013/14 seasons, respectively. The application of the fungicide, thiram, to the seed at planting in the 2012/13 season greatly improved emergence and plant stand. In error, no fungicide was applied to the seed in the 2013/14 season.

Plant population increased significantly with increasing seeding rate in the 2012/13 season (Figure 3.3). A significant interaction was measured between the seeding rates and cultivars for plant population in the 2013/14 season, but not in the 2012/13 season (Table 3.4). AGS 353 and AGS 354 had significantly lower plant populations than Lightning and AGS 292 at seeding rates from 100 000 to 250 000 seeds ha^{-1} (Figure 3.4).

Significant positive correlations were measured between plant population ha^{-1} and plant height, bottom pod height and the number of pods ha^{-1} (Table 3.15). Significant negative correlations were measured between plant population ha^{-1} and the number of branches $plant^{-1}$, percentage export marketable pods, the number of pods with seeds $plant^{-1}$ and 100-seed mass.

TABLE 3.4 ANOVA table of plant population for the cultivars and seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	0.75	NS	5 660.5	-
Seeding rate	604.04	**	8 005.2	-
Cultivar x seeding rate	0.38	NS	13 865.4	7.0
2013/14 season				
Cultivar	119.13	**	5 647.9	-
Seeding rate	399.60	**	6 917.2	-
Cultivar x seeding rate	14.24	**	13 834.4	9.0

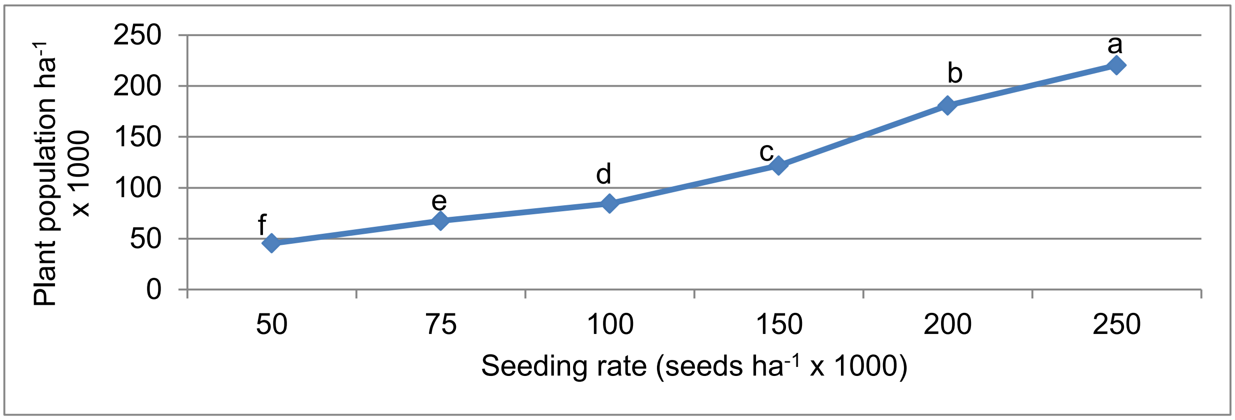

FIGURE 3.3 Mean plant population ha^{-1} of the three cultivars at the various seeding rates in the 2012/13 season

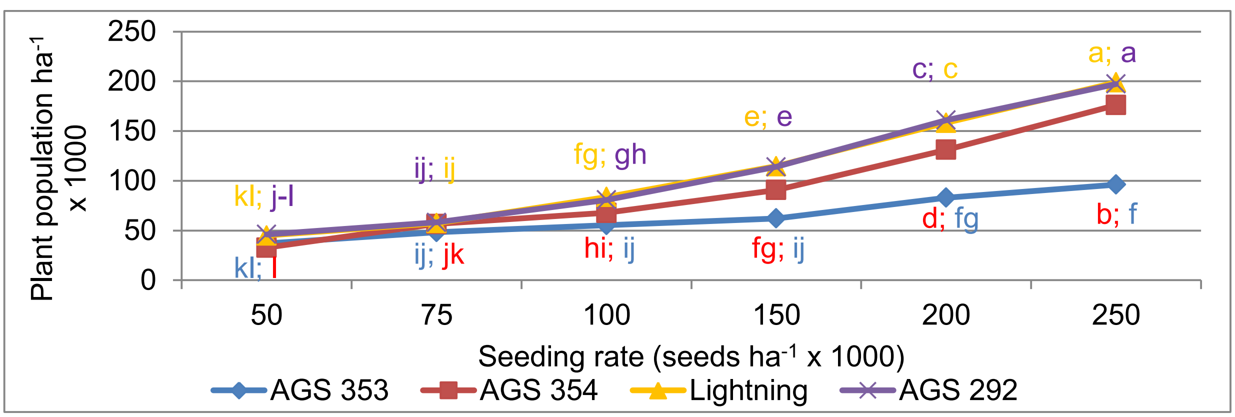

FIGURE 3.4 Plant population of four cultivars at six seeding rates in the 2013/14 season

3.4.4 Plant height and bottom pod height

In both seasons, significant differences in plant height were measured between the cultivars and the seeding rates, but no significant interactions were measured between the cultivars and seeding rates (Table 3.5). AGS 292, which had the shortest plants and the lowest bottom pod height (Figures 3.7 and 3.12), did not canopy in the 0.75 m wide rows, which allowed weeds to grow (Figure 3.9). Lightning had the tallest plants with the highest bottom pod height in both seasons (Figures 3.5, 3.7 and 3.10). Plant height and bottom pod height increased significantly with increasing seeding rates in both seasons (Figures 3.6, 3.8 and 3.11). In the 2012/13 season mean plant height increased significantly as seeding rate increased from 50 000 seeds ha^{-1} to 200 000 seeds ha^{-1} (Figures 3.6). In the 2013/14 season mean plant height increased significantly as the seeding rate increased from 75 000 to 150 000 seeds ha^{-1} (Figure 3.8).

A significant interaction was measured between the cultivars and seeding rates for bottom pod height in the 2013/14 season (Table 3.6). At 50 000 seeds ha^{-1}, AGS 354 had significantly lower bottom pod heights than AGS 353 and Lightning (Figure 3.12). However, at 200 000 and 250 000 seeds ha^{-1}, AGS 353 had significantly lower bottom pod heights than Lightning and AGS 354, and Lightning, respectively. AGS 292 had significantly lower bottom pod heights at all six seeding rates than the other three cultivars.

Significant positive correlations were measured between plant height and seed yield ha^{-1}, plant population ha^{-1}, bottom pod height, the number of branches $plant^{-1}$, percentage export marketable pods, the number of pods with seeds $plant^{-1}$ and the number of pods ha^{-1} (Table 3.15). A significant negative correlation was measured between plant height and 100-seed mass.

Significant positive correlations were measured between bottom pod height and seed yield ha^{-1}, plant population ha^{-1}, plant height and the number of pods ha^{-1}, whilst a significant negative correlation was measured between bottom pod height and 100-seed mass (Table 3.15).

TABLE 3.5 ANOVA table of plant height for the various cultivars and six seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	21.09	**	4.54	-
Seeding rate	239.47	**	3.21	-
Cultivar x seeding rate	0.92	NS	7.86	7.6
2013/14 season				
Cultivar	578.07	**	2.74	-
Seeding rate	20.99	**	3.36	-
Cultivar x seeding rate	1.81	NS	6.72	6.4

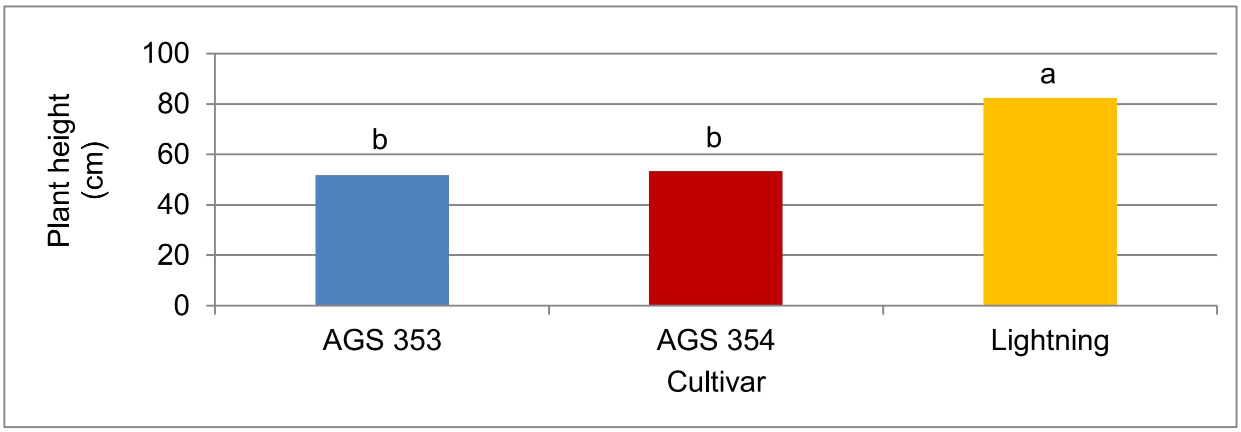

FIGURE 3.5 Mean plant height of the three cultivars in the 2012/13 season

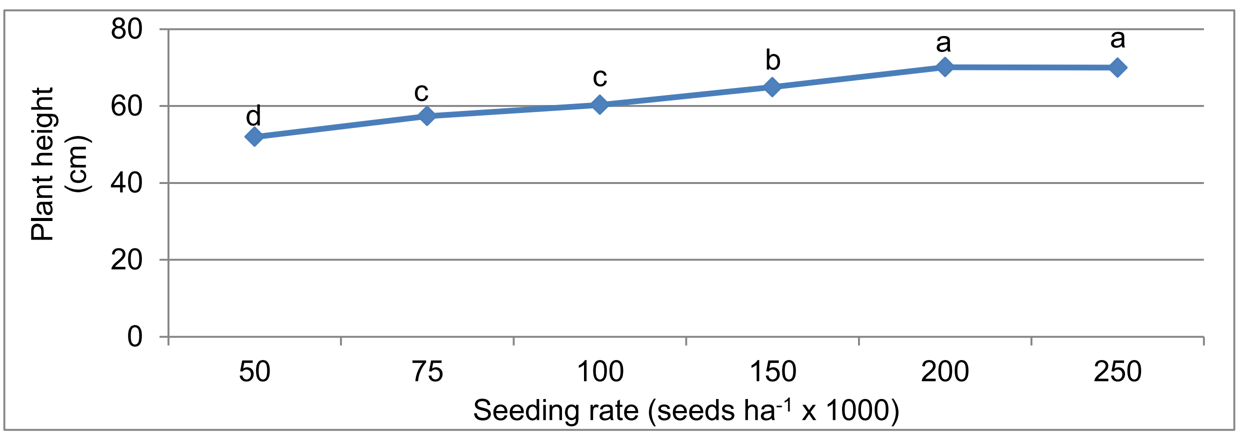

FIGURE 3.6 Plant height of the three cultivars at various seeding rates in the 2012/13 season

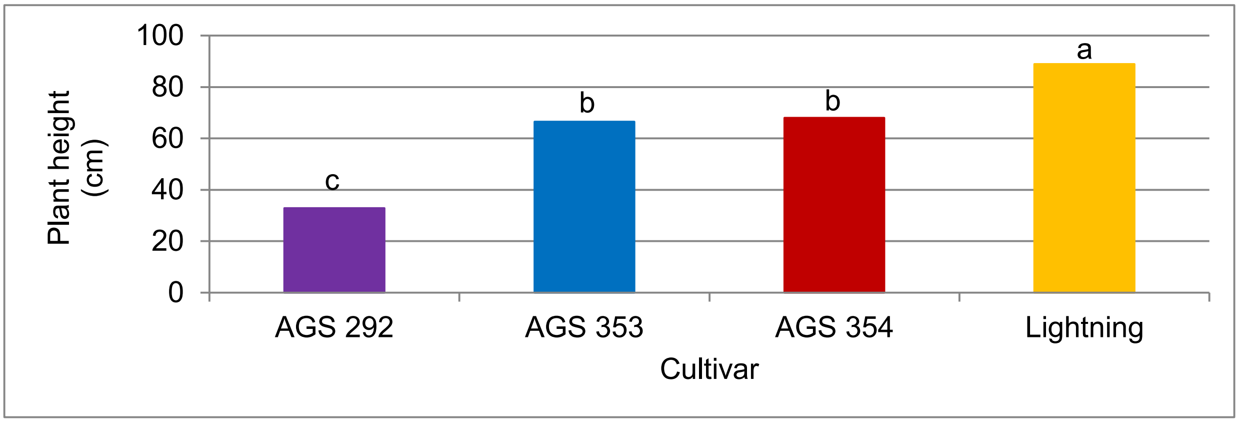

FIGURE 3.7 Mean plant height of the four cultivars in the 2013/14 season

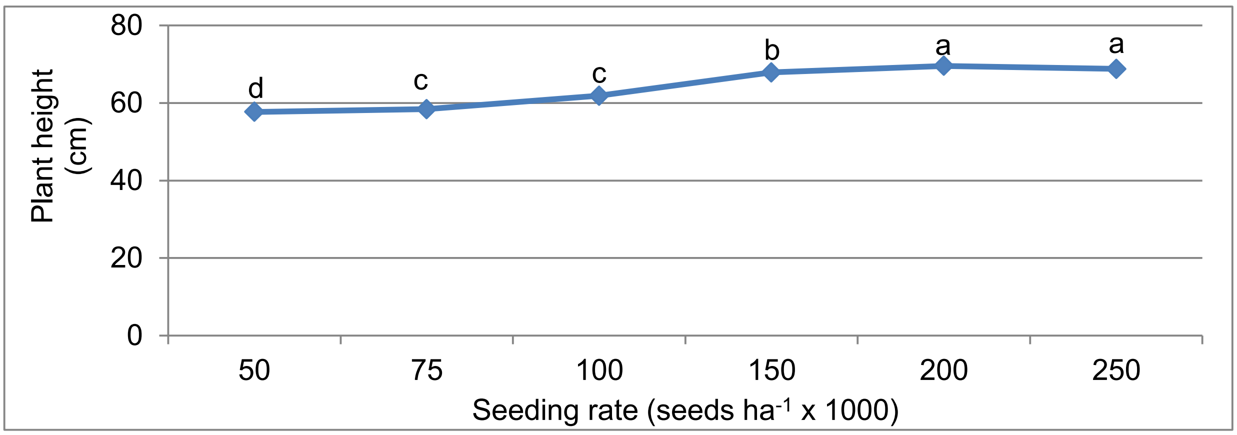

FIGURE 3.8 Plant height of the four cultivars at various seeding rates in the 2013/14 season.

FIGURE 3.9 Mature AGS 292 plants in the foreground and Lightning in the background. Note the weeds resulting from poor canopy closure in the 0.75 m wide rows.

TABLE 3.6 ANOVA table of bottom pod height for the various cultivars and six seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	19.42	**	1.02	-
Seeding rate	55.33	**	1.45	-
Cultivar x seeding rate	0.80	NS	2.51	11.8
2013/14 season				
Cultivar	103.05	**	1.24	-
Seeding rate	30.19	**	1.52	-
Cultivar x seeding rate	2.33	*	3.04	14.5

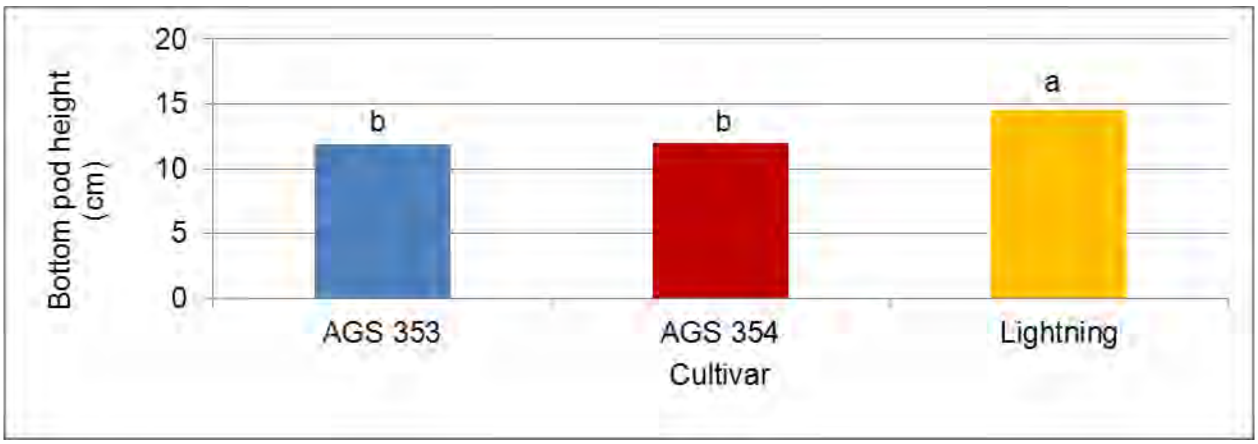

FIGURE 3.10 Mean bottom pod height of the three cultivars in the 2012/13 season

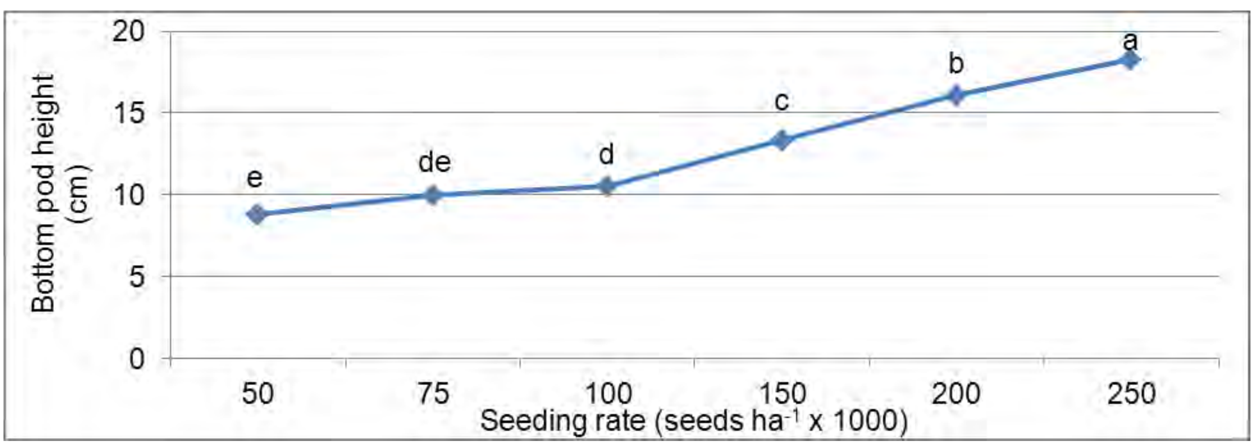

FIGURE 3.11 Bottom pod height of the three cultivars at various seeding rates in the 2012/13 season

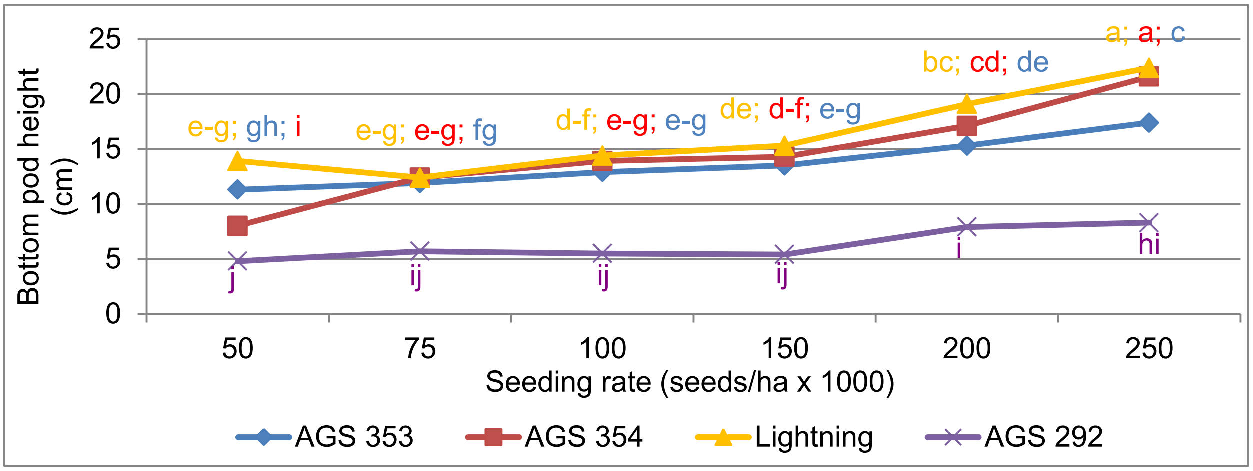

FIGURE 3.12 Bottom pod height for four cultivars at six seeding rates in the 2013/14 season

3.4.5 Branches

The number of branches plant^{-1} decreased significantly with increasing seeding rate from 50 000 to 250 000 seeds ha^{-1} in both seasons (Figure 3.14). Lightning had the highest number of branches plant^{-1} in the 2012/13 season (Figure 3.13), whilst AGS 292 had the least number of branches plant^{-1} in the 2013/14 season (Figure 3.15). In the 2013/14 season a significant interaction was measured between the cultivars and seeding rates for the number of branches plant^{-1} (Table 3.7). AGS 292 had significantly fewer branches plant^{-1} than the other cultivars at all the seeding rates (Figure 3.15). At 50 000 seeds ha^{-1} Lightning had significantly more branches plant^{-1} than AGS 353. However, from 150 000 to 250 000 seeds ha^{-1} Lightning had significantly fewer branches than AGS 353. At 200 000 and 250 000 seeds ha^{-1}, AGS 353 had significantly more branches plant^{-1} than AGS 354.

Significant positive correlations were measured between the number of branches plant^{-1} and seed yield ha^{-1}, plant height, number of pods with seeds plant^{-1} and number of pods ha^{-1} (Table 3.15). Significant negative correlations were measured between the number of branches plant^{-1} and plant population ha^{-1} and 100-seed mass.

TABLE 3.7 ANOVA table of number of branches plant^{-1} for the cultivars and seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	25.03	**	0.56	-
Seeding rate	14.34	**	0.79	-
Cultivar x seeding rate	1.26	NS	1.38	12.4
2013/14 season				
Cultivar	158.89	**	0.38	-
Seeding rate	26.97	**	0.47	-
Cultivar x seeding rate	4.27	**	0.94	11.8

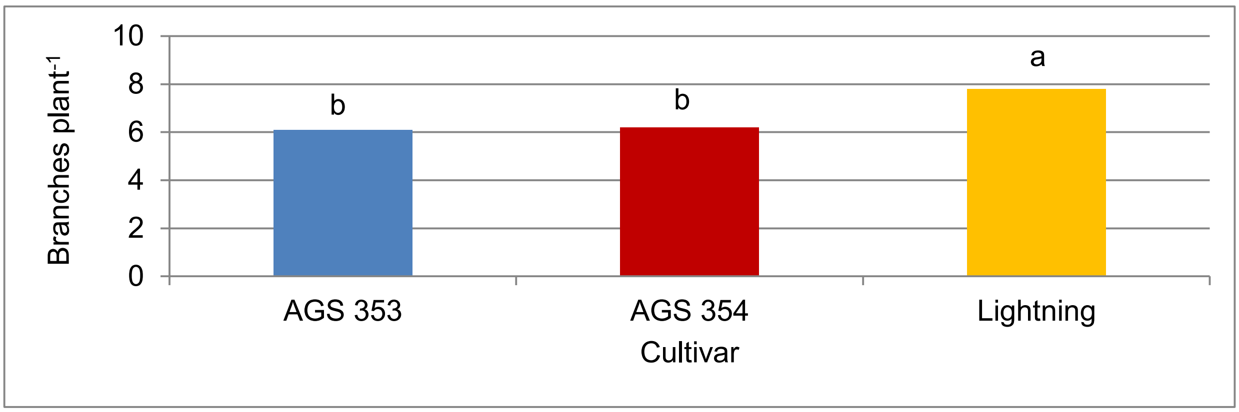

FIGURE 3.13 Number of branches plant^{-1} for the three cultivars in the 2012/13 season

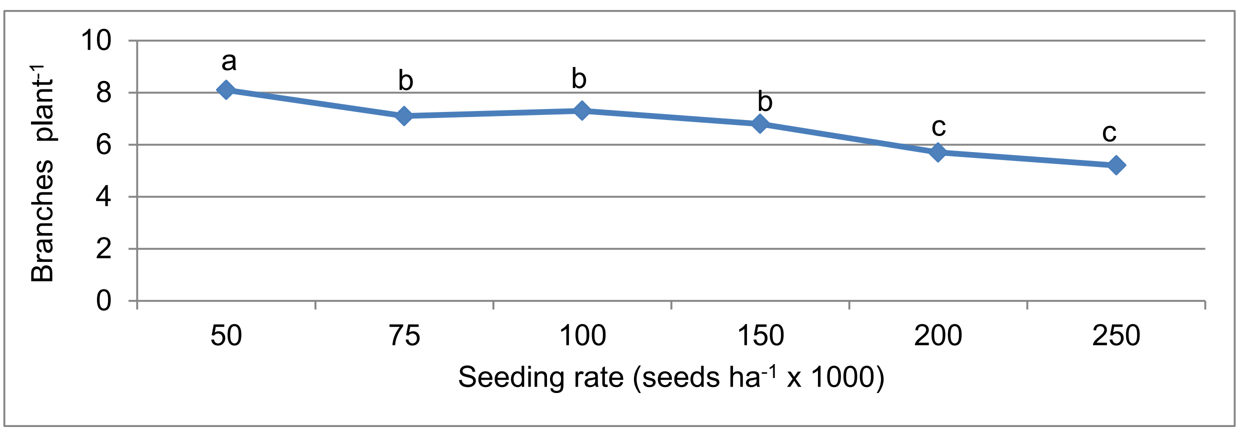

FIGURE 3.14 Number of branches plant^{-1} at various seeding rates in the 2012/13 season

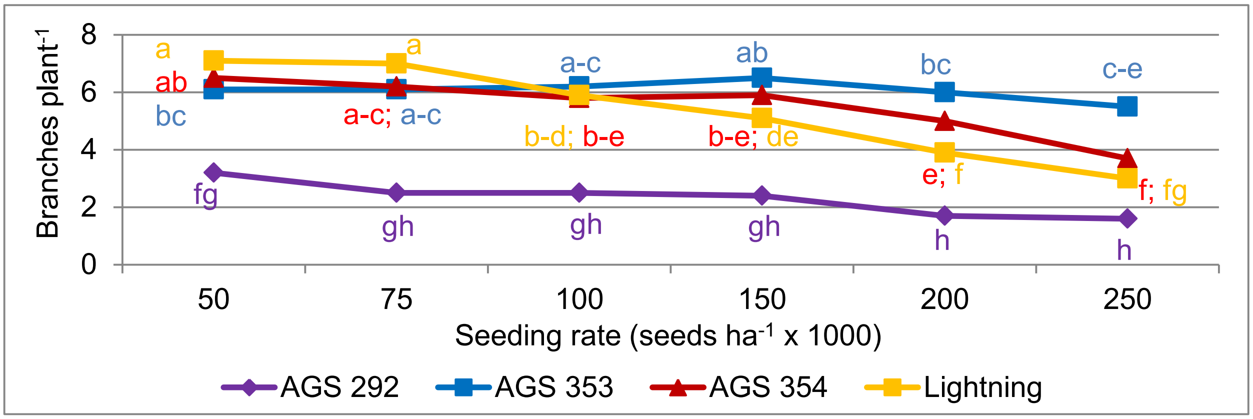

FIGURE 3.15 Number of branches plant^{-1} for four cultivars at six seeding rates in the 2013/14 season

3.4.6 Pods per plant

Significant interactions were measured between the cultivars and seasons for number of pods plant^{-1} (Table 3.8). In the 2012/13 season, Lightning produced significantly more pods plant^{-1} at all seeding rates than AGS 353 and AGS 354, between which no significant difference was measured (Figure 3.16). In the 2013/14 season, Lightning produced significantly more pods plant^{-1} than AGS 353 and AGS 354 at 50 000 and 75 000 seeds ha^{-1}, but from 100 000 to 250 000 seeds ha^{-1}, the differences were non-significant (Figure 3.17). AGS 292 had significantly fewer pods plant^{-1} from 50 000 to 200 000 seeds ha^{-1} than the other three cultivars. In the 2012/13 season, AGS 353 and AGS 354 produced a similar number of pods plant^{-1} at all seeding rates. However, in the 2013/14 season AGS 353 produced significantly more pods plant^{-1} than AGS 354 at seeding rates from 75 000 seeds ha^{-1} and above. This was possibly due to the lower plant population of AGS 353 at those seeding rates. In both seasons, the number of pods plant^{-1} decreased significantly as seeding rate increased (Figures 3.16 and 3.17).

Significant positive correlations were measured between the number of pods plant^{-1} and plant height, number of branches plant^{-1}, percentage export marketable pods, number of pods ha^{-1} and seed yield, whilst significant negative correlations were measured with plant population ha^{-1} and 100-seed mass (Table 3.15).

TABLE 3.8 ANOVA table of number of pods plant^{-1} for the various cultivars and seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	179.97	**	5.67	-
Seeding rate	73.84	**	8.02	-
Cultivar x seeding rate	5.17	**	13.88	12.4
2013/14 season				
Cultivar	109.25	**	6.66	-
Seeding rate	77.00	**	8.16	-
Cultivar x seeding rate	8.16	**	16.32	16.5

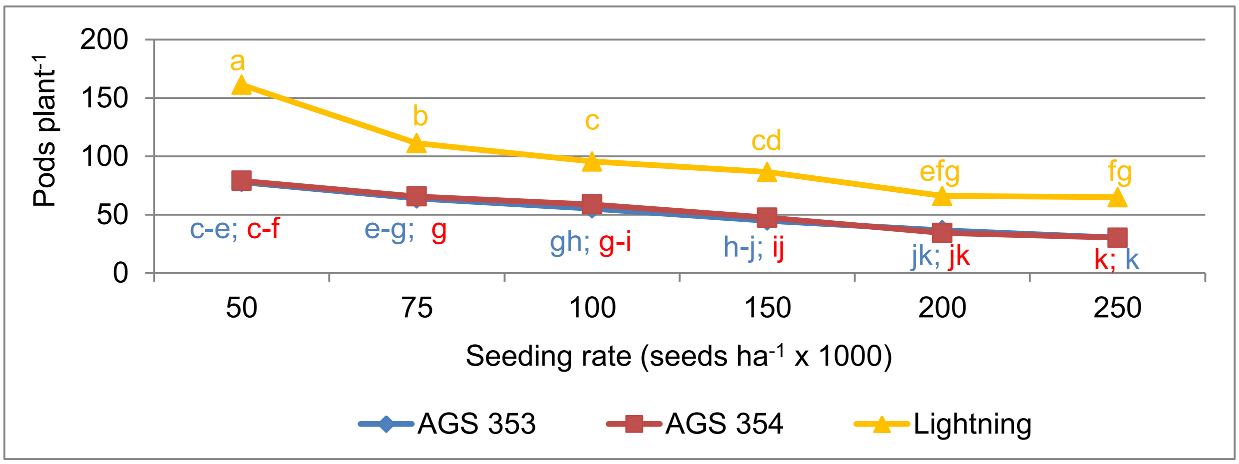

FIGURE 3.16 Number of pods plant^{-1} for three cultivars at six seeding rates in the 2012/13 season

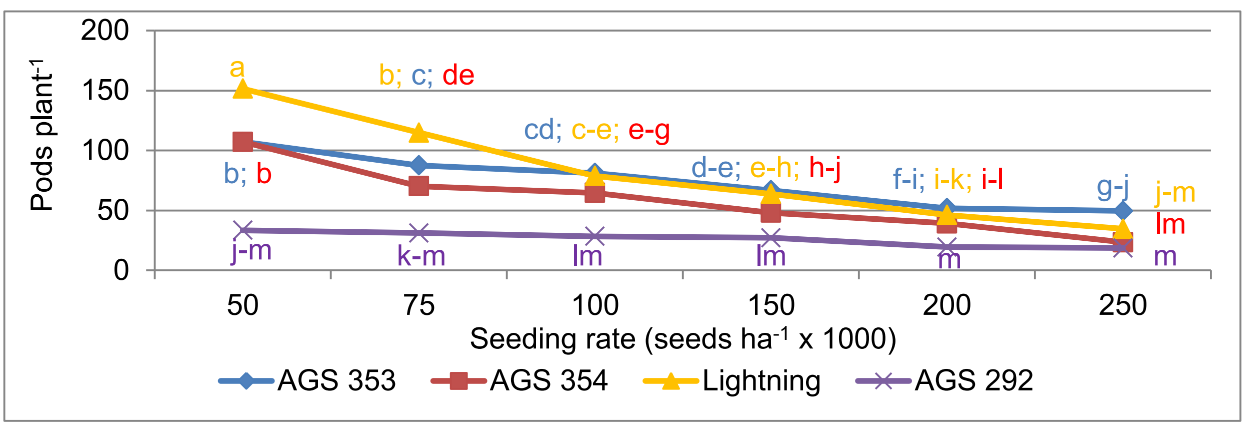

FIGURE 3.17 Number of pods plant^{-1} for four cultivars at six seeding rates in the 2013/14 season

3.4.7 Export marketable pods*

No significant interaction for export marketable pods was measured between the cultivars and seeding rates in the 2012/13 season (Table 3.10). Lightning had a significantly lower mean percentage export marketable pods than AGS 353 and AGS 354 (Figure 3.18). At 200 000 and 250 000 seeds ha^{-1} significantly lower percentages of export marketable pods were measured than from 50 000 to 150 000 seeds ha^{-1} (Figure 3.19).

A significant interaction for export marketable pods was measured between the cultivars and seeding rates in the 2013/14 season (Table 3.10). At seeding rates from 50 000 to 100 000 seeds ha^{-1}, AGS 292 had significantly lower percentages of export marketable pods than the other cultivars (Figure 3.20). At 150 000 seeds ha^{-1} AGS 353 had a significantly higher percentage of export marketable pods than the other cultivars, whilst at 200 000 and 250 000 seeds ha^{-1} AGS 353 and Lightning had significantly higher percentages of export marketable pods ha^{-1} than AGS 354 and AGS 292.

Significant positive correlations were measured between percentage export marketable pods and plant height, total pods with seeds $plant^{-1}$ and seed yield (Table 3.15). A significant negative correlation was measured between percentage export marketable pods and plant population.

TABLE 3.10 ANOVA table of percentage export marketable pods for the various cultivars at the various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	4.44	*	2.05	-
Seeding rate	4.81	**	2.90	-
Cultivar x seeding rate	1.55	NS	5.02	4.2
2013/14 season				
Cultivar	21.49	**	2.29	-
Seeding rate	2.57	*	2.81	-
Cultivar x seeding rate	2.53	*	5.61	4.5

*Export marketable pods are pods containing two or more beans. The length and width of the pods have not been considered, although they are important charcteristics to meet the requirements of the export market.

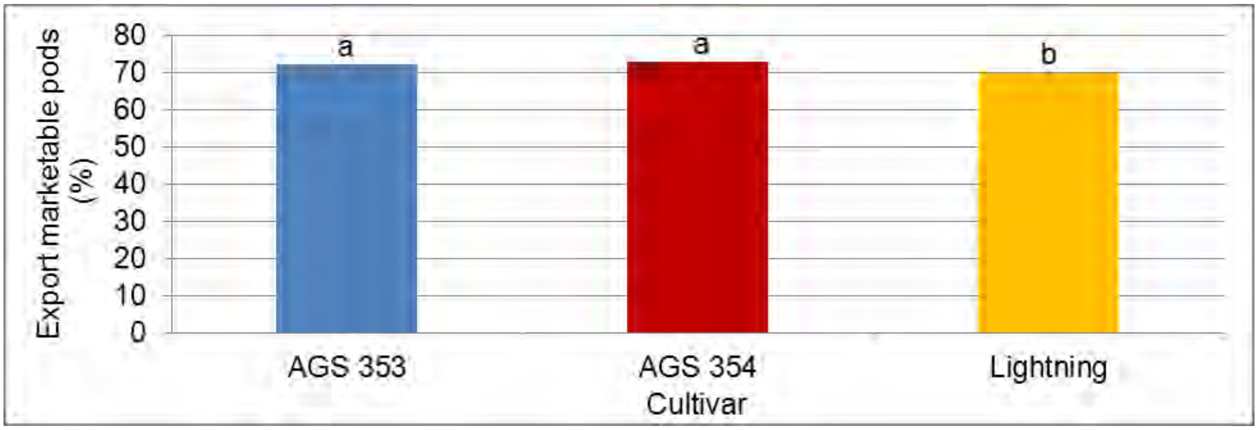

FIGURE 3.18 Percentage export marketable pods for the three cultivars in the 2012/13 season

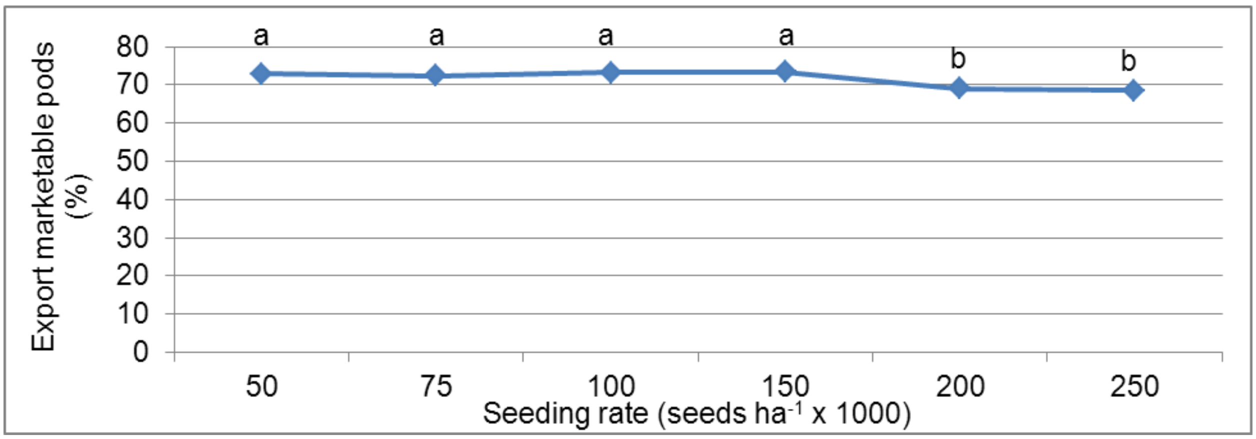

FIGURE 3.19 Mean percentage export marketable pods of the three cultivars at the various seeding rates in the 2012/13 season

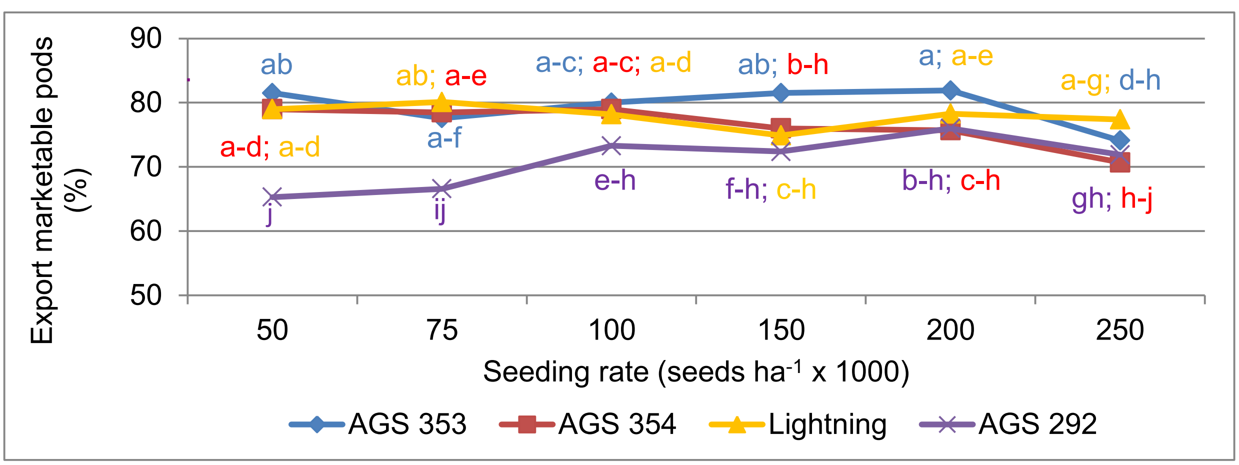

FIGURE 3.20 Percentage export marketable pods of four cultivars at the various seeding rates in the 2013/14 season

3.4.8 Pods per hectare

A significant interaction was measured for the number of pods ha^{-1} between the cultivars and seeding rates in the 2012/13 season (Table 3.11). At all seeding rates, Lightning produced significantly more pods ha^{-1} than AGS 353 and AGS 354, between which no significant differences were measured (Figure 3.21).

No significant interaction was measured for the number of pods ha^{-1} between the cultivars and seeding rates in the 2013/14 season (Table 3.11). Lightning and AGS 292 produced significantly more and less pods ha^{-1}, respectively, than the other two cultivars (Figure 3.22). In both seasons the number of pods ha^{-1} increased significantly with increasing seeding rates (Figure 3.3).

Significant positive correlations were measured between the number of pods ha^{-1} and plant population ha^{-1}, plant height, bottom pod height and the number of branches $plant^{-1}$, but a significant negative correlation was measured with 100-seed mass (Table 3.15).

TABLE 3.11 ANOVA table of number of pods ha^{-1} for the various cultivars and various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	252.45	**	475.0	-
Seeding rate	55.35	**	671.7	-
Cultivar x seeding rate	7.05	**	1163.5	10.4
2013/14 season				
Cultivar	89.90	**	899.7	-
Seeding rate	7.29	**	1101.9	-
Cultivar x seeding rate	1.31	NS	2203.7	18.3

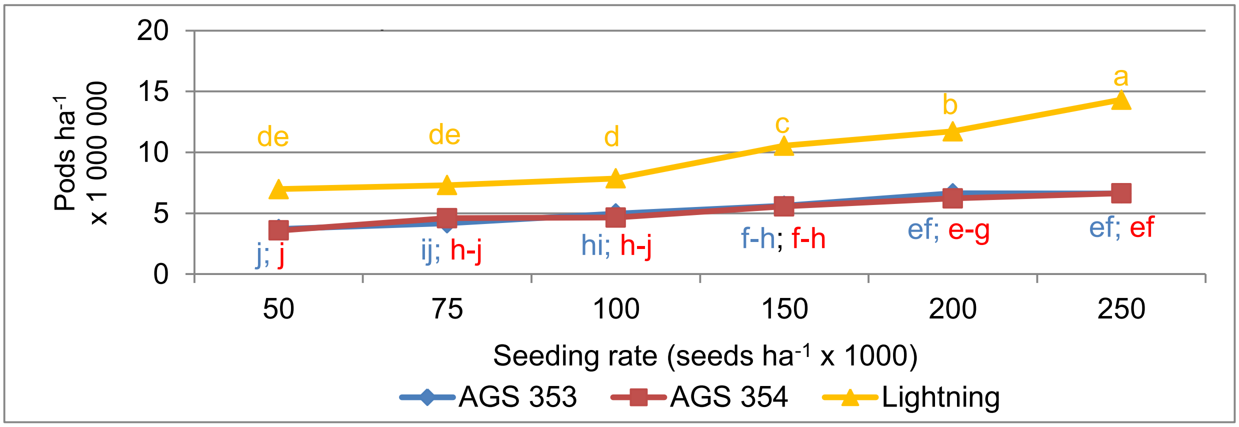

FIGURE 3.21 Number of pods ha^{-1} for the three cultivars at the various seeding rates in the 2012/13 season

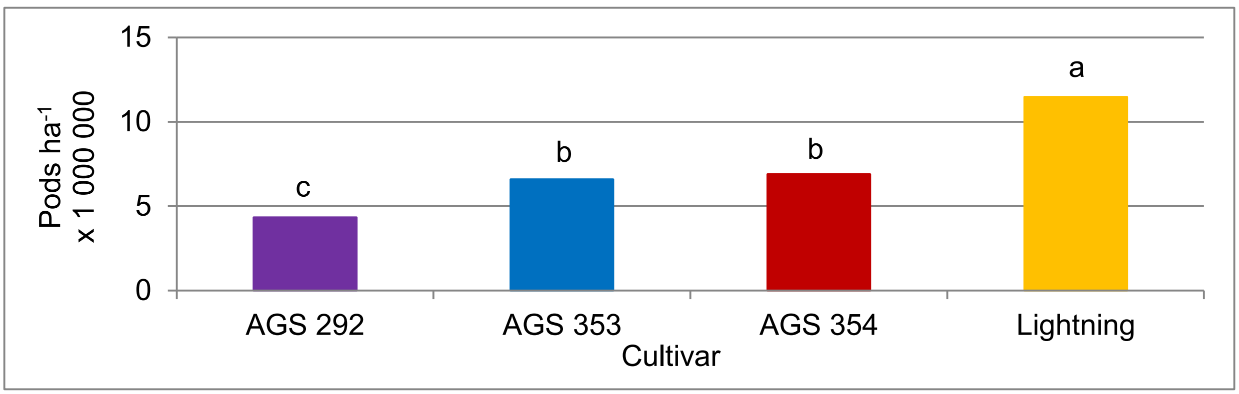

FIGURE 3.22 Number of pods ha^{-1} for the four cultivars in the 2013/14 season

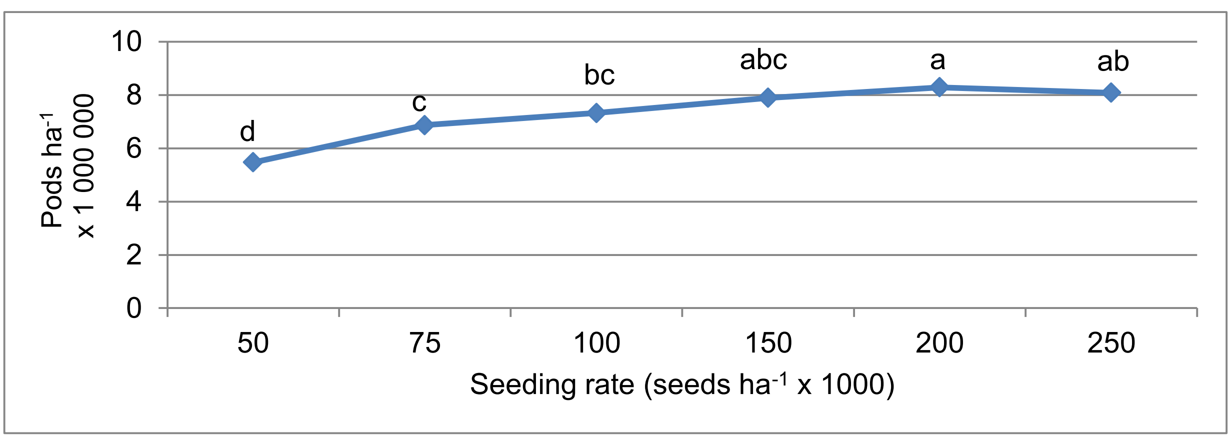

FIGURE 3.23 Mean number of pods ha^{-1} at the various seeding rates in the 2013/14 season

3.4.9 Seed mass

No significant interactions were measured between the cultivars and seeding rates for 100-seed mass in both seasons (Table 3.12). In the 2012/13 season no significant differences in 100-seed mass were measured among the seeding rates. However, in the 2013/14 season significantly higher 100-seed masses were measured at 50 000 and 150 000 seeds ha^{-1} than at the other four seeding rates (Figure 3.26). Lightning produced significantly lower 100-seed masses than the other three cultivars in both seasons (Figures 3.24 and 3.25).

Significant negative correlations were measured between 100-seed mass and plant population ha^{-1}, plant height, bottom pod height, the number of branches $plant^{-1}$, the number of pods with seeds $plant^{-1}$ and the number of pods ha^{-1} (Table 3.15). No significant correlation was measured between 100-seed mass and seed yield ha^{-1}.

TABLE 3.12 ANOVA table of 100-seed mass for the cultivars and various seeding rates for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
2012/13 season				
Cultivar	70.17	**	2.05	-
Seeding rate	1.20	NS	2.89	-
Cultivar x seeding rate	0.46	NS	5.01	7.6
2013/14 season				
Cultivar	125.47	**	2.15	-
Seeding rate	7.28	**	2.63	-
Cultivar x seeding rate	0.91	NS	5.26	7.7

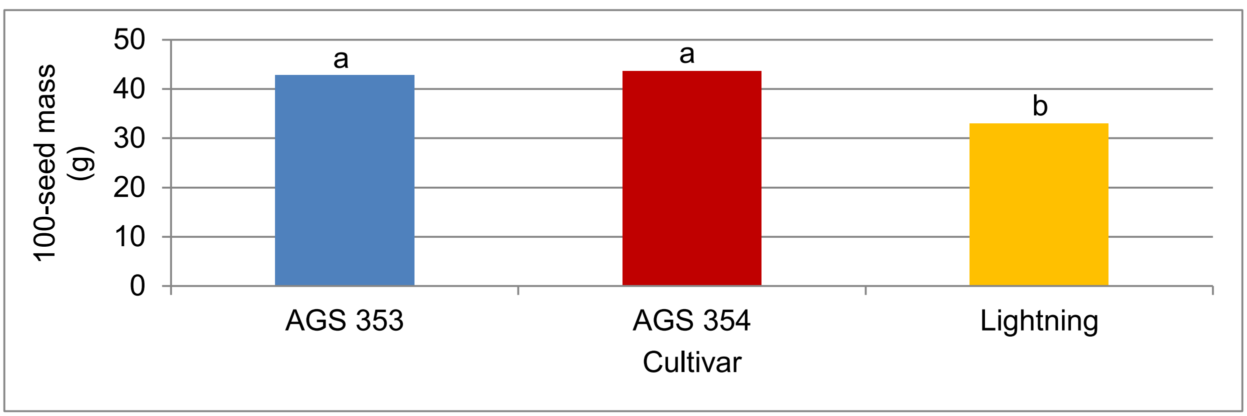

FIGURE 3.24 100-seed mass of the three cultivars in the 2012/13 season

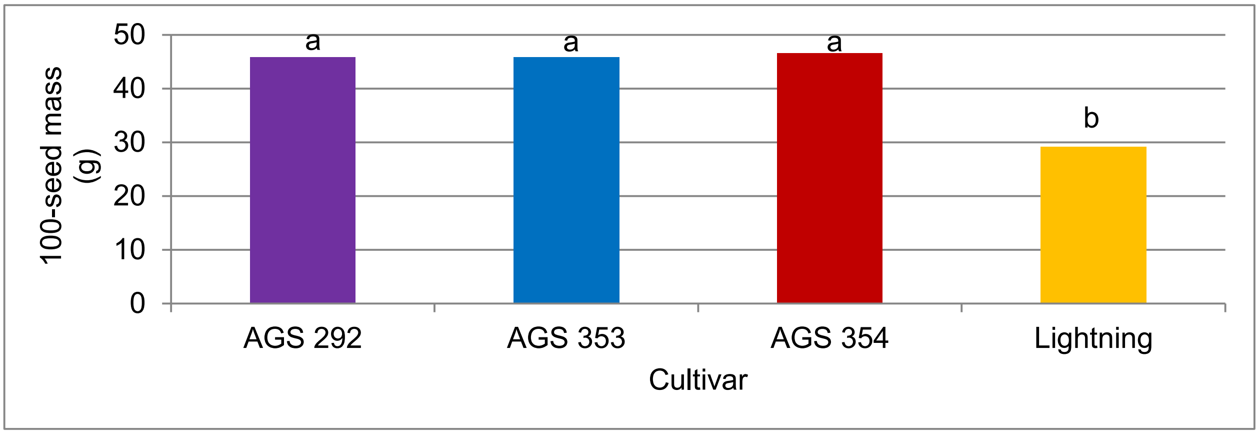

FIGURE 3.25 100-seed mass of the four cultivars in the 2013/14 season

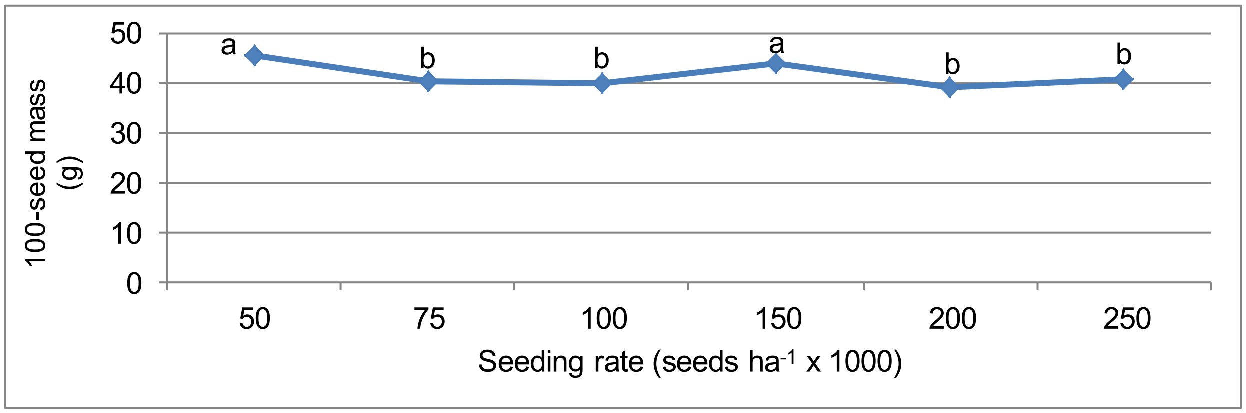

FIGURE 3.26 100-seed mass at various seeding rates in the 2013/14 season

3.4.10 Yield

No significant interaction for seed yield was measured between the cultivars and seeding rates in the 2012/13 season (Table 3.13). However, a significant interaction was measured in the 2013/14 season. AGS 292 produced significantly higher yields at seeding rates from 150 000 to 250 000 seeds ha^{-1} than at seeding rates from 50 000 to 150 000 seeds ha^{-1} (Figure 3.27). At seeding rates from 50 000 to 200 000 seeds ha^{-1}, AGS 292 produced significantly lower yields than the other three cultivars. At 250 000 seeds ha^{-1} the yield of AGS 292 was not significantly different to those produced by AGS 354 and Lightning. At 75 000 seeds ha^{-1} AGS 353 produced a significantly higher yield than AGS 354 and Lightning, whilst at 250 000 seeds ha^{-1} the yield was significantly higher than that produced by Lightning.

In both seasons, seeding rate had no significant effect on yield (Table 3.13).

A significant interaction was measured between the cultivars, AGS 353, AGS 354 and Lightning, and the seasons (Table 3.13). Lightning produced a significantly higher yield in the 2012/13 season than in the 2013/14 season, whilst AGS 353 and AGS 354 produced significantly higher yields in the 2013/14 season than in the 2012/13 season (Figure 3.28). No significant interaction was measured between the cultivars and seeding rates for mean seed yield for the two seasons. However, Figure 3.29 indicates that Lightning produced optimally at a seeding rate of 50 000 seeds ha^{-1}, whilst AGS 353 and AGS 354 produced optimally at seeding rates of 75 000 and 150 000 seeds ha^{-1}, respectively.

Seed yield was significantly positively correlated to plant height, bottom pod height, the number of branches $plant^{-1}$, percentage export marketable pods, the number of pod $plant^{-1}$ and the number of pods ha^{-1} (Table 3.15). No significant negative correlations were measured with seed yield.

TABLE 3.13 ANOVA table of seed yield for the various cultivars and various seeding rates for two trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
2012/13 season				
Cultivar	11.63	**	270.4	-
Seeding rate	1.42	NS	382.5	-
Cultivar x seeding rate	2.01	NS	662.4	12.1
2013/14 season				
Cultivar	65.52	**	282.7	-
Seeding rate	1.07	NS	346.3	-
Cultivar x seeding rate	2.69	**	692.5	13.6
2012/13 and 2013/14 seasons (3 cultivars)				
Season	1.60	NS	403.0	-
Cultivar	2.00	NS	199.1	-
Seeding rate	1.25	NS	281.6	-
Season x cultivar	16.47	**	410.9	-
Season x seeding rate	0.69	NS	481.7	-
Cultivar x seeding rate	1.15	NS	487.7	-
Season x cultivar x seeding rate	1.74	NS	732.0	12.5

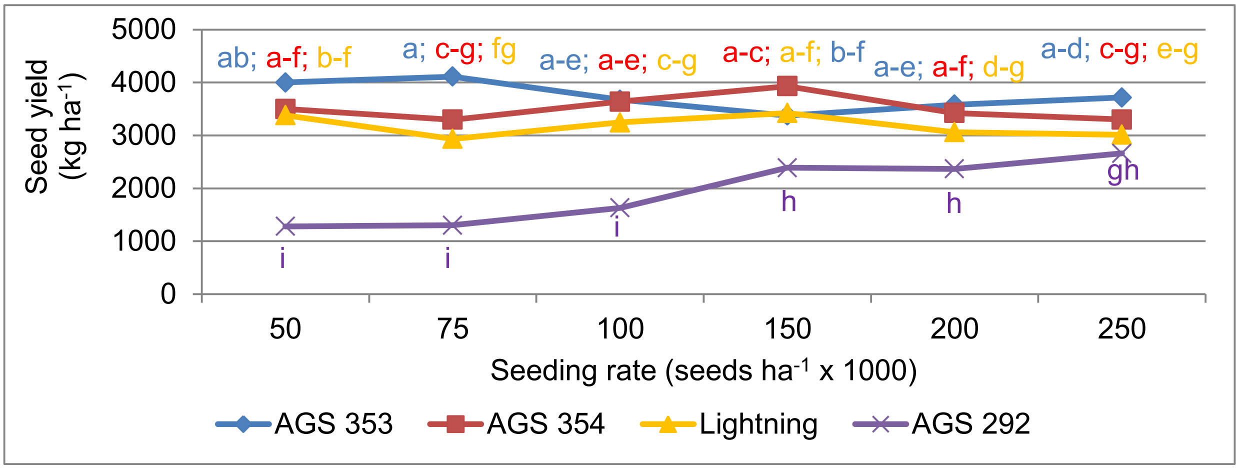

FIGURE 3.27 Seed yield of four vegetable soybean cultivars at various seeding rates in the 2013/14 season

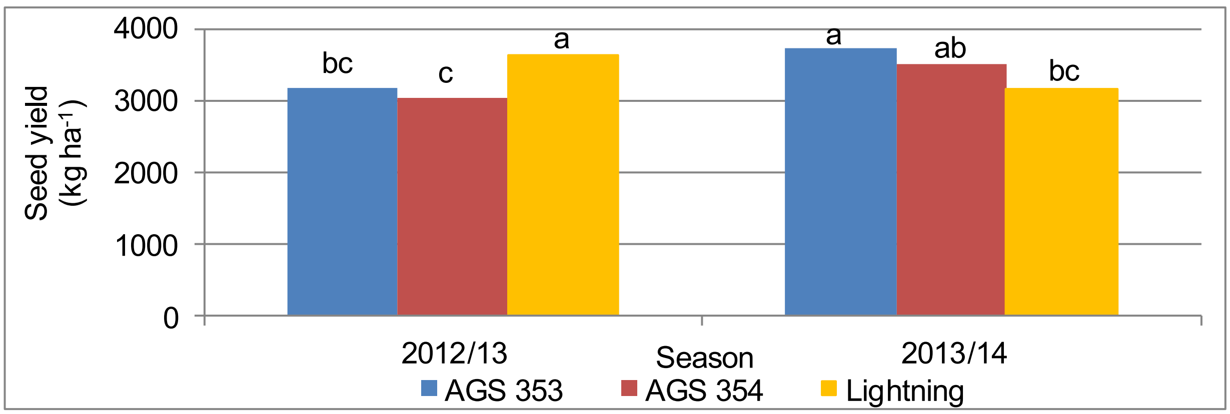

FIGURE 3.28 Seed yield for three cultivars in two seasons

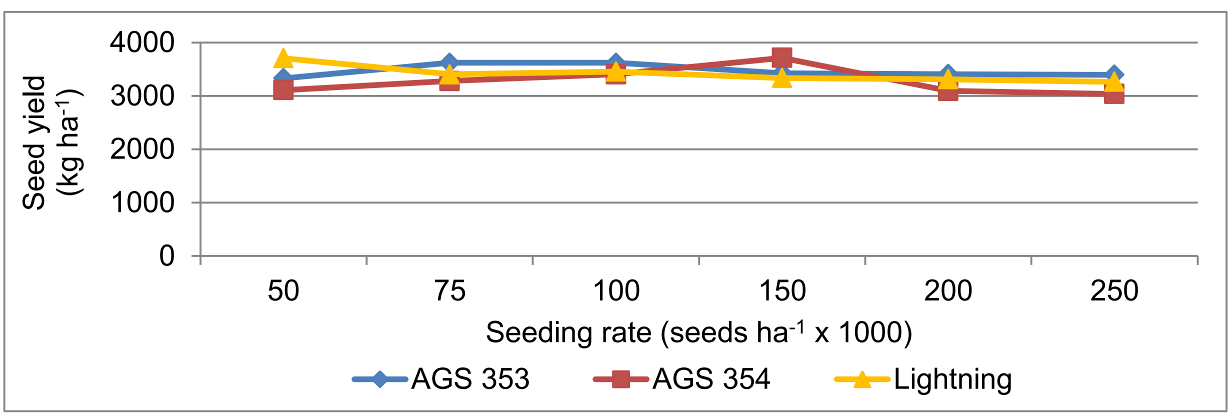

FIGURE 3.29 Mean seed yield of three cultivars at various seeding rates for the 2012/13 and 2013/14 seasons (Note: there was no significant interaction between the cultivars and seeding rates, but the figure indicates where the optimum seeding rate is for each cultivar).

3.4.11 Seed cost

The seed quantity and cost per hectare at an estimated price of R35 kg^{-1} for the seed weighing 40 g 100 $seeds^{-1}$ is reflected in Table 3.14.

TABLE 3.14 Seed quantity and price per hectare at the various seeding rates

	Seeding rate					
	50	**75**	**100**	**150**	**200**	**250**
			(seeds ha^{-1} x 1000)			
Seed (kg ha^{-1})	20	30	40	60	80	100
Price (R ha^{-1})	700	1050	1400	2100	2800	3500

3.4.12 Correlations

The cultivars AGS 353, AGS 354 and Lightning were used to determine the correlation coefficients between the various agronomic characteristics measured over the 2012/13 and 2013/14 seasons (Table 3.15).

TABLE 3.15 Correlation coefficients measured for various agronomic characters pooled from three cultivars and two seasons

	Seed yield ha^{-1}	Plant population ha^{-1}	Plant height (cm)	Bottom pod height (cm)	Number of branches plant^{-1}	Export marketable pods (%)	Pods with seeds plant^{-1}	Number of pods ha^{-1}
Plant population ha^{-1}	-0.073 NS	---	---	---	---	---	---	---
Plant height (cm)	0.548 **	0.197 *	---	---	---	---	---	---
Bottom pod height (cm)	0.370 **	0.571 **	0.755 **	---	---	---	---	---
Number of branches plant^{-1}	0.579 **	-0.416 **	0.398 **	-0.052 NS	---	---	---	---
Export marketable pods (%)	0.408 **	-0.363 **	0.209 *	-0.021 NS	0.144 NS	---	---	---
Pods with seeds plant^{-1}	0.379 **	-0.589 **	0.410 **	-0.033 NS	0.514 **	0.421 **	---	---
Number of pods ha^{-1}	0.364 **	0.356 **	0.852 **	0.638 **	0.197 *	0.085 NS	0.400 **	---
100-seed mass (g)	-0.064 NS	-0.179 *	-0.610 **	-0.406 **	-0.209 *	0.050 NS	-0.310 **	-0.671 **

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

3.5 DISCUSSION

The total rainfall received in the 2012/13 season was almost similar to the long-term mean and was more evenly distributed than in the 2013/14 season (Table 3.1). However, the high rainfall received in March 2014, which coincided with pod-fill, consequently resulted in a higher mean yield in the 2013/14 season than in the 2012/13 season for the three cultivars, AGS 353, AGS 354 and Lightning, which were evaluated in both seasons (Figure 3.28).

Although Lightning received less rainfall from 50% flowering to harvest maturity than AGS 353 and AGS 354 in the 2012/13 season, it received more rainfall towards the end of grain-fill and the growing conditions were cooler. Consequently Lightning yielded significantly better than AGS 353 and AGS 354 in the 2012/13 season (Table 3.2).

In the 2013/14 season the yields increased with increasing amounts of rainfall. Lightning received less rainfall during late pod-fill and consequently produced a significantly lower yield than AGS 353 and AGS 354. Although AGS 353 and AGS 354 received the same quantity of rainfall in each season, AGS 353 yielded better, but the differences were not significant. Soybean is sensitive to water stress, but tolerates dry conditions better than maize (Liebenberg, 2012). Comlekcioglu and Simsek (2011) reported that at least equal to or excess of the evaporated water amount was required to produce high yields. Demirtaş *et al*. (2010) reported that water deficits during the reproductive development stages, pod elongation and particularly during pod-filling reduced seed yield significantly, but not during the vegetative growth stages. Popovic *et al*. (2013) reported that yield was positively correlated to the quantity and distribution of rainfall, but negatively correlated to temperature. Therefore, to optimise production and economic return, irrigation is recommended when insufficient rainfall is received, especially during the reproductive growth stages.

AGS 292, which did not benefit from the abundant rainfall received during March 2014, due to a short growing-season, and had to compete with weeds, produced significantly lower yields than the other cultivars at rates of 50 000 to 200 000 seeds ha^{-1} (Figure 3.27). The weed competition was greater at the lower seeding rates and therefore significantly lower yields were produced from 50 000 to 100 000 seeds ha^{-1} than at the higher seeding rates. Zhang and Kyei-Boahen (2007) reported that short-season cultivars generally produce lower yields than longer-seasons cultivars. Higher seeding rates in close rows are therefore recommended for short-season cultivars (Edwards *et al*., 2005; Christmas, 2008).

In both seasons the monthly mean maximum temperatures from December to April were warmer than the long-term mean (Table 3.3), whilst the monthly mean minimum temperatures were similar. The high mean maximum temperatures recorded in January and February 2014 may have affected certain yield components and seed yield, because flowering and early pod development occurred during these months. Soybean production is optimized at 25°C (Liebenberg, 2012), whilst heat stress will occur above 29.4˚C (Puteh *et al.*, 2013). Heat stress during flowering can result in pollen sterility and reduced pod set. However, heat stress during the R5 growth stage (beginning of seed development) will have the greatest impact on yield, due to decreased seed mass (Lindsey and Thomison, 2012). Puteh *et al*. (2013) reported that the extent of yield reduction was influenced by the duration of heat stress, particularly during the reproductive stages. The authors added that vegetable soybean is more sensitive to high temperatures than grain soybean.

The temperatures during the growing-season influenced the DAP to 50% flowering and harvest maturity for the cultivars in each season (Figures 3.1 and 3.2). Warmer conditions during November and December 2012 resulted in all the cultivars flowering earlier than in the 2013/14 season. In the 2013/14 season Lightning experienced warmer conditions during pod-fill than in the 2012/13 season and consequently reached harvest maturity earlier.

The application of the fungicide, thiram, to the seed at planting in the 2012/13 season may have resulted in the higher plant stand than in the 2013/14 season when no fungicide was applied (Figures 3.3 and 3.4), whilst the significant variations in plant population between the cultivars may have been due to seed quality. Xue *et al*. (2007) reported a similar increase in plant population with the application of thiram. AGS 353 and, to a lesser extent, AGS 354, had significantly lower mean plant populations than AGS 292 and Lightning in the 2013/14 season. Duppong and Hatterman-Valenti (2005), Sanchez *et al*. (2005) and Hamilton (2007) reported inconsistent plant stands with some cultivars in certain seasons. The reason for this could have been due to poor seed quality resulting from in-field pod fungal diseases or poor post-harvest storage. Seed size may have also contributed to low plant stands. Lightning and AGS 292 had smaller seed sizes than AGS 353 and AGS 354 at planting. Khalil *et al*. (2001) and Adebisi *et al*. (2013) reported that smaller grain soybean seeds produced higher germination and emergence percentages than medium and large seeds, whilst Rezapour *et al*. (2013) reported that medium sized seeds produced higher germination percentages than small and large sized seeds, but the effect was non-significant. Edamame seeds, with a range from 25 – 50 g 100^{-1} seeds, are considerably larger than grain soybean seed, which has 16 – 17 g 100^{-1} seeds. A total of 44 mm of rain was received three and four days after planting the trials in the 2013/14 season and should have been sufficient to ensure good germination.

As plant population increased, plant height, bottom pod height and number of pods ha^{-1} increased significantly, whilst the number of branches and pods $plant^{-1}$ decreased significantly. Christmas (2008) and Epler and Staggenborg (2008) reported a similar relationship with plant height, bottom pod height and plant population. This result was due to increased competition for sunlight among the plants as plant population increased. Cultivar growing-season length also had a significant positive effect on plant height and bottom pod height, as confirmed by Hamilton (2007), Zhang and Kyei-Boahen (2007) and Swathi (2009). The long-season cultivar, Lightning, had significantly taller plants (Figures 3.5 and 3.7) and higher bottom pod heights (Figures 3.10 and 3.12), whilst the short-season cultivar, AGS 292, had significantly shorter plants and lower bottom pod heights than the other cultivars. No significant differences were measured for mean plant height and bottom pod height between AGS 353 and AGS 354 in both seasons. In the seasons, mean plant height increased significantly from 50 000 seeds ha^{-1} to 200 000 seeds ha^{-1} (Figures 3.6 and 3.8), whilst bottom pod height increased significantly from 50 000 seeds ha^{-1} to 250 000 seeds ha^{-1} (Figures 11 and 12).

A disadvantage of low plant populations is low bottom pod heights, which may result in yield losses when mechanical harvesting is done (Zandonadi, 2009). Pods below 0.12 m may not be harvested depending on the type of harvester (Liebenberg, 2012). The short-season cultivars will be more affected than the medium- and long-season cultivars due to their short stature.

Due to the short plant height of AGS 292, the crop did not canopy at the row spacing of 0.75 m and weeds competed with the soybean plants (Figure 3.9). A combination of higher seeding rates (Christmas, 2008) and narrower rows (De Bruin and Pedersen, 2008 (b)) will result in quicker canopy closure and improved yields of short-season cultivars, especially when planted late in the season (Ball *et al.*, 2001). Full canopy cover should occur before flowering. This will reduce evaporation from the soil and reduce weed growth (Liebenberg, 2012).

Significant positive correlations were measured between plant height and percentage export marketable pods and seed yield ha^{-1}. Sarutayophat (2012) measured significant positive correlations between plant height and the number of marketable pods plant^{-1} and marketable pod yield, but measured a significant negative correlation between plant height and green pod weight, indicating that taller cultivars tend to produce smaller pods. Significant negative correlations were measured between plant height and 100-seed mass and between the number of pods ha^{-1} and 100-seed mass (Table 3.15).

The number of branches plant^{-1} decreased significantly with increasing seeding rate from 50 000 to 250 000 seeds ha^{-1} in both seasons (Figures 3.14 and 3.15), thus confirming the results obtained by Christmas (2008), Swathi (2009), Herman (2010) and Sharma (2013). Sharma (2013) reported that three to four branches plant^{-1} were desirable for optimum production. In both seasons AGS 353, AGS 354 and Lightning had ≥ 3 branches plant^{-1} at all the seeding rates and had a mean of 6.7 and 5.6 branches plant^{-1} in the 2012/13 and 2013/14 seasons, respectively. AGS 292 only had > 3 branches plant^{-1} at 50 000 seeds ha^{-1}. A significant negative correlation was measured between plant population and the number of branches plant^{-1} (Table 3.15). However, a higher mean number of branches plant^{-1} was recorded in the 2012/13 season, despite the higher plant population.

Christmas (2008) and Epler and Staggenborg (2008) reported that the number of pods on both the main stem and branches decreased as seeding rate increased, indicating the significance of branching at lower seeding rates. Suhre (2012) reported higher pod yields from the branches at lower seeding rates than at higher seeding rates with grain soybean. Significant positive correlations were measured between the number of branches plant^{-1} and the number of pods plant^{-1} and seed yield (Table 3.15).

In the 2012/13 season no significant interaction was measured between the cultivars and seeding rates for the number of branches plant^{-1}. However, Lightning had significantly more branches plant^{-1} than AGS 353 and AGS 354, between which there was no significant difference (Figure 3.13). A significant positive correlation was measured between plant height and the number of branches plant^{-1} (Table 3.15), indicating that taller cultivars produce more branches. Swathi (2009) reported a similar trend.

In the 2013/14 season a significant interaction was measured between the cultivars and seeding rates for the number of branches plant^{-1} (Figure 3.15). AGS 292 produced significantly fewer branches plant^{-1} than the other cultivars at all seeding rates. At 50 000 seeds ha^{-1} Lightning produced significantly more branches plant^{-1} than AGS 353. However, from 150 000 to 250 000 seeds ha^{-1} Lightning produced significantly fewer branches plant^{-1} than AGS 353. The rapid decline in the number of branches plant^{-1} produced by Lightning as seeding rate increased from 75 000 seeds ha^{-1} indicates that this long-season cultivar is more sensitive to higher seeding rates than cultivars with a shorter growing-season. At 200 000 and 250 000 seeds ha^{-1}, AGS 354 produced significantly fewer branches plant^{-1} than AGS 353, due to significantly higher plant populations at those seeding rates than AGS 353 (Figure 3.4).

A significant negative correlation was measured between plant population and the number of pods plant^{-1} and percentage export marketable pods (Table 3.15). Haifeng (2006) and Sharma (2013) reported a similar trend. Planting at low seeding rates will be beneficial, because the plants will grow shorter and produce more branches bearing more pods, thus making them more attractive to customers who wish to buy the whole plant. Fewer „unmarketable" one-seeded pods will be produced, which will be economically beneficial when marketing green pods.

As cultivar growing-season length increased, significantly more pods plant^{-1} were produced, thus confirming the result reported by Zhang and Kyei-Boahen (2007). In both seasons significant interactions with the cultivars and seeding rates were measured for the number of pods plant^{-1}. In the 2012/13 season the long-season cultivar, Lightning, produced significantly more pods plant^{-1} at all the seeding rates than the medium-season cultivars, AGS 353 and AGS 354, between which no significant differences were measured (Figure 3.16). At 250 000 seeds ha^{-1} the number of pods ha^{-1} produced by Lightning was not significantly different to the number of pods ha^{-1} produced by AGS 353 at 50 000 seeds ha^{-1} and by AGS 353 and AGS 354 at 75 000 and 100 000 seeds ha^{-1}. In the 2013/14 season, AGS 353 produced a significantly higher mean number of pods plant^{-1} than AGS 354, due to significantly more pods plant^{-1} at seeding rates from 75 000 to 150 000 seeds ha^{-1} and at 250 000 seeds ha^{-1} (Figure 3.17) and a significantly lower mean plant population. The number of pods plant^{-1} produced by Lightning was not significantly different to the number of pods produced by AGS 353 and AGS 354 from 100 000 to 250 000 seeds ha^{-1}. AGS 292 produced a significantly lower mean number of pods plant^{-1} than the other cultivars, due to a lower mean number of branches plant^{-1} (Figure 3.15), a shorter growing season and weed competition. No significant differences in the number of pod plant^{-1} were measured among the seeding rates for AGS 292, indicating greater stability across the seeding rates for this cultivar. Lightning displayed the greatest decline in the number of pods plant^{-1} with increasing seeding rate in both seasons (Figures 3.16 and 3.17). This result confirms the significant positive correlation measured between the number of branches plant^{-1} and the number of pods plant^{-1} (Table 3.15). At 250 000 seeds ha^{-1} the number of pods plant^{-1} produced by AGS 292, AGS 354 and Lightning were not significantly different in the 2013/14 season.

A significant negative correlation was measured between plant population and percentage export marketable pods (Table 3.15). In the 2012/13 season the percentage export marketable pods (≥ 2 seeds pod^{-1}) was significantly lower at seeding rates of 200 000 and 250 000 seeds ha^{-1} than at the other seeding rates, among which there were no significant differences. AGS 353 and AGS 354 produced significantly higher mean percentages of export marketable pods than Lightning. Christmas (2008) reported that the number of seeds pod^{-1} did not change much with variations in plant population.

However, in the 2013/14 season AGS 353 produced a significantly higher mean percentage of export marketable pods than AGS 354 and AGS 292, but not with Lightning. The lower plant population of AGS 353 may have contributed to this result. AGS 292 produced a significantly lower mean percentage of export marketable pods than the other cultivars due to the effect of the weeds, especially at the lower seeding rates of 50 000 and 75 000 seeds ha^{-1}. In the 2013/14 season a significant interaction was measured between the cultivars and seeding rates. A significantly lower mean percentage export marketable pods was recorded at 250 000 seeds ha^{-1} than at 100 000 and 200 000 seeds ha^{-1}.

Bekele and Alemahu (2011) reported that the number of seeds pod^{-1} was the greatest contributor to grain soybean yield, followed by the number of pods plant^{-1}. Percentage export marketable pods and the number of pods plant^{-1} were significantly correlated to seed yield (Table 3.15). Kantolic and Slafer (2007) reported that yield was highly correlated to the number of seeds produced per unit area.

The number of pods ha^{-1} increased significantly with increasing seeding rate in both seasons (Figures 3.21 and 3.23) and significant positive correlations were measured between the number of pods ha^{-1} and plant population and seed yield (Table 3.15). Nelson *et al*. (2002) reported that marketable green pod yield increased from 99 000 to 247 000 plant ha^{-1}, but the result was non-significant. In the 2012/13 season a significant interaction was measured for the number of pods ha^{-1} between the cultivars and seeding rates (Table 3.11). Lightning produced significantly more pods ha^{-1} at each seeding rate than AGS 353 and AGS 354, between which there were no significant differences. At 250 000 seeds ha^{-1} the number of pods ha^{-1} produced by AGS 353 and AGS 354 were not significantly different to the number of pods ha^{-1} produced by Lightning at 50 000 and 75 000 seeds ha^{-1}.

In the 2013/14 season no significant interaction was measured between the cultivars and seeding rates for number of pods ha^{-1}. The number of pods ha^{-1} increased with increasing seeding rate, but no significant differences were measured from 150 000 to 250 000 seeds ha^{-1} (Figure 3.23) further indicating the negative impact high seeding rates have on edamame prodction.

No significant interactions were measured between the cultivars and seeding rates for 100-seed mass in both seasons. In the 2012/13 season no significant differences in 100-seed mass were measured among the six seeding rates. In the 2013/14 season significantly higher mean 100-seed masses were recorded at 50 000 and 150 000 seeds ha^{-1} than at the other seeding rates. The high 100-seed mass at 150 000 seeds ha^{-1} was unexpected. In both seasons 100-seed mass was highest at a seeding rate of 50 000 seeds ha^{-1}.

For export quality purposes, a dry 100-seed mass of ≥ 30 g is required. Seed size is genetically determined, but influenced by growing conditions (Duppong and Hatterman-Valenti, 2005; Liu *et al*., 2010; Carson *et al*., 2011). In both seasons Lightning produced significantly lower 100-seed masses than the other three cultivars, among which no significant differences were measured. In the 2013/14 season the 100-seed mass of Lightning did not always meet the export market quality requirements of ≥ 30 g 100-seed^{-1} (dry). Sharma (2013) measured a significant negative correlation between the number of days to flowering and 100-seed mass, whilst Swathi (2009) measured a significant negative correlation between plant height and 100-seed mass, which was also measured in the experiment (Table 3.15). Lightning had the longest growing-season, the tallest plants and the lowest 100-seed mass. However, this result does not apply to all long-season cultivars. The black-seeded long-season cultivars, Tanba and Tanbaguro, produce considerably larger seeds than Lightning.

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James (2007) reported that the seed size of the cultivar, C784, was not affected by seeding rates from 50 000 to 200 000 seeds ha^{-1}, but seed size generally decreased linearly from 50 000 to 400 000 seeds ha^{-1}. Lightning produced a higher 100-seed mass in the 2012/13 season than in the 2013/14 season, due to the higher rainfall received during late grain-fill. No significant correlation was measured between 100-seed mass and seed yield. However, Swathi (2009) measured a significant positive correlation between 100-seed mass and green pod yield.

Suhre (2012) reported that soybean plants compensate for lower seeding rates by producing higher seed yields on the stems and branches. The number of seeds pod^{-1} is an important factor in the marketing of edamame. For export quality requirements the pods should contain ≥ 2 seeds pod^{-1}. The percentage export marketable pods, the number of pods $plant^{-1}$ and the number of pods ha^{-1} were significantly positively correlated to seed yield. Epler and Staggenborg (2008), Bekele and Alemahu (2011), Comlekcioglu and Simsek (2011), Sarutayophat (2012) and Sharma (2013) reported similar results. Although the number of pods ha^{-1} increased with increasing seeding rates, the plants produced more pods containing more seeds on the stems and branches at decreasing seeding rates, thus resulting in no significant differences in yield being measured among the various seeding rates for AGS 353, AGS 354 and Lightning.

Hamilton (2007) recommended seeding rate targets of 148 000 to 173 000 seeds ha^{-1}. The mean yield of the three cultivars over the two seasons indicated that the optimal seeding rate was 100 000 seeds ha^{-1}, which was recommended by Birch (2002) for KwaZulu-Natal. However, the results here indicated that Lightning, AGS 353 and AGS 354 yielded best at 50 000, 75 000 and 150 000 seeds ha^{-1}, respectively (Figure 3.29). Planting at these lower seeding rates will reduce the seed cost (De Bruin and Pedersen, 2008 (a and b)), thus making the crop more profitable.

AGS 292 produced significantly lower yields than the other three cultivars at all the seeding rates, except at 250 000 seeds ha^{-1}, when compared with AGS 354 and Lightning, indicating that higher seeding rates are required for short-season cultivars (Edwards *et al*., 2005; Christmas, 2008). Therefore, seeding rates ≥ 250 000 seed ha^{-1} may be necessary, together with an inter-row spacing < 0.75 m, for optimum yields to be obtained by short-season cultivars in KwaZulu-Natal and/or to produce the same yields as medium- and long-season cultivars. Further research evaluating the combination of seeding rate and inter-row spacing on yield is required for short-season cultivars.

Overall, seeding rate and plant population had no significant effect on seed yield. Factors contributing significantly to yield were quantity of rainfall received during pod-fill, plant height, the number of branches plant^{-1}, percentage export marketable pods, the numbers of pods plant^{-1} and pods ha^{-1}, as confirmed by Kantolic and Slafer (2007), Epler and Staggenborg (2008), Demirtaş *et al*. (2010), Bekele and Alemahu (2011), Comlekcioglu and Simsek (2011), Suhre (2012) and Sarutayophat (2012). Lee *et al*. (2008) and Zhang *et al*. (2010) recommended higher seeding rates with late planting dates, because the number of pods plant^{-1} and yield decline, due to a shorter pod-fill period resulting from warmer temperatures. However, Egli and Bruening (2002), Christmas (2008) and Zhang *et al*. (2010) reported that the yield from short-season soybean cultivars was more stable at late planting dates and therefore seeding rates did not need to be increased.

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CHAPTER 4

VEGETABLE SOYBEAN CULTIVAR EVALUATION

4.1 ABSTRACT

Twenty vegetable soybean (*Glycine max* (L.) Merrill) cultivars were evaluated under dryland conditions in four experiments during the 2010/11, 2011/12 and 2012/13 seasons on a Hutton soil at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), KwaZulu-Natal, South Africa. Two experiments were planted a month apart in the 2012/13 season. The experiments used a randomized complete block design with three replicates. Each plot consisted of four rows of 5 m length with an inter-row spacing of 0.75 m. Fertilizer was applied according to the KwaZulu-Natal Department of Agriculture and Rural Development‟s Analytical Services‟ recommendations for optimum yields based on the analyses of soil samples taken from each site. The seeds were inoculated with *Bradyrhizobium japonicum* Kirchner and were hand-planted at a seeding rate of 266 667 seeds ha^{-1}. Due to seasonal variations in rainfall quantity and distribution, hail damage and plant population, significant interactions between the seasons and cultivars were measured for all the agronomic characteristics studied. The shorter-season cultivars in both plantings in the 2012/13 season were more severely disadvantaged by hail damage on 31 December 2012 and consequently produced lower yields than the longer-season cultivars, which had more recovery time. The plant population in the second planting of 2012/13 was greatly reduced by the hail. Further variations in plant population over the seasons were due to a poor emergence of some cultivars. The application of thiram as a fungicide seed coating at planting in the 2012/13 season may possibly have resulted in the significantly higher plant population than in the 2010/11 and 2011/12 seasons when thiram was not applied. With longer growing-season cultivars, significantly higher green pod, green bean and seed yields were produced. Yields were significantly and positively correlated to plant population, plant height, the number of branches $plant^{-1}$, number of pods $plant^{-1}$, percentage marketable pods (≥ 2 beans pod^{-1}), shelling percentage and percentage fat, but negatively correlated to 100-seed mass. Mean fresh green bean yields ranged from 3.62 t ha^{-1} for the short-season cultivar, AGS 292, to 6.66 t ha^{-1} for the long-season cultivar, Lightning.

Key words: Edamame, cultivar, plant population, yield

4.2 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill), also known as edamame, originated in China, but is now grown worldwide and is marketed as green pods or green beans. Taste and quality, as defined by crude protein and fat content, are therefore important factors. The beans must be tender and have a nuttier and slightly sweeter flavour than grain soybean. However, seed size (≥ 30 g 100 dry seeds^{-1}), number of beans pod^{-1} (≥ 2) and pod size (1.3 cm wide and 4.5 cm long) are also important, especially for the export market (Palada and Ma, 2012). Other factors to consider are plant height, bottom pod height and standability. However, these characteristics, which are genetically determined, will be affected by the prevailing growing conditions. The best adapted cultivar will therefore be one that provides the highest yield and quality over the long term (Liebenberg, 2012; de Beer and de Klerk, 2014).

Individual cultivars may demonstrate limited adaptation to specific areas due to their sensitivity to photoperiod as affected by latitude and planting date. A cultivar will mature later and demonstrate a lengthened growing-season the further south it is planted in southern Africa. Planting dates will also affect the length of the growing-season. A cultivar will flower earlier if planted at a later date. In warmer areas, it will grow and mature quicker than in cooler areas. Growing-season length is therefore an important characteristic to consider when selecting cultivars (Liebenberg, 2012; de Beer and de Klerk, 2014).

Unlike grain soybean, which is a major crop in South Africa, vegetable soybean is relatively unknown, but may have the potential as a cash crop for both small-scale and commercial farmer production. Before introducing a new crop, it is essential to conduct research on it to determine whether the crop is adapted to the prevailing environmental conditions and is economically viable. One important aspect is to identify suitable cultivars for specific areas.

The harvest window of vegetable soybean as a green pod is narrow (Duppong and Hatterman-Valenti, 2005). To ensure market continuity for as long as possible, a selection of cultivars with various growing-season lengths should be grown (Carson *et al*, 2011) and/or sequential plantings should be conducted (James, 2007). It is therefore important to evaluate a wide selection of cultivars with varying growing-season lengths in as many bioclimatic areas as possible over at least three seasons.

The objective of this study was to evaluate twenty vegetable soybean cultivars grown under dry-land conditions in the KwaZulu-Natal Midlands for plant height, bottom pod height, number of branches plant^{-1}, number of seeds pod^{-1}, number of pods plant^{-1}, 100-seed mass, crude protein and fat content, shelling percentage and green pod, green bean and seed yields.

4.3 MATERIALS AND METHODS

A field experiment was conducted over three seasons, from October 2010 to May 2013, at the Cedara Research Station of the KwaZulu-Natal Department of Agriculture and Rural Development (KZNDARD), South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The mean annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2010 to 2013 was received from the automatic weather station of the Agricultural Research Council – Institute of Soil, Climate and Water (ARC-ISCW) on the Cedara Research Station. The soil was a Hutton form with an orthic A over a red apedal B and had a depth > 1 m. Soil analyses showed an average of 46% clay and 3.1% organic carbon. The average pH (KCl) and acid saturation during the experimental period was 4.7% and 1.6%, respectively.

4.3.1 Land preparation

Due to the need for crop rotation, different lands were used each season. The lands had been planted to maize in the preceding seasons. Soil samples were taken from each land during July or August of the same planting year and analyzed by the Fertilizer Advisory Services" Laboratories of the KZN DARD based on the Cedara Research Station.

The lands were cultivated twice with a tractor-drawn offset disc-harrow in spring. Prior to planting, a tractor-drawn konskilde was used.

4.3.2 Fertilization and planting

Based on the results of the soil samples, 20 kg ha^{-1} phosphorous, as single superphosphate (10.5% P), was hand-applied in the rows, which were opened using a hand-held V-shaped hoe to a depth of approximately 0.05 m. No additional nutrients were applied. The fertilizer was covered by a layer of soil. The seeds were then hand-placed in the row at an intra-row spacing of 0.05 m, resulting in a seeding rate of 266 666 seeds ha^{-1}. A seed inoculant, *Bradyrhizobium japonicum* Kirchner, was mixed into water in a 16 litre knapsack and sprayed onto the seed.

Immediately after application, the seed was covered with approximately 0.02 - 0.03 m of soil using a hand-held rake. Twenty cultivars were evaluated. Nineteen were bred by the AVRDC - The World Vegetable Center in Taiwan, and one cultivar, "Lightning", was of unknown origin. Sixteen of the AVRDC cultivars were obtained from The Edamame Development Program[1] and three from the Agricultural Research Council – Grain Crops Institute[2]. The experiments were planted on 3 November 2010, 29 November 2011, 12 November 2012 and 12 December 2012. Two experiments were implemented in 2012 to determine the effect of planting date on cultivar performance.

4.3.3 Weed, insect and disease control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[3]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[4]) were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. The post-emergence herbicides bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) and fluazifop-P-butyl (Fusilade Super® EC, 125 g a.i. L^{-1}, Syngenta) were applied five weeks after planting at 1440 and 600 g a.i. ha^{-1}, respectively, with a knap-sack sprayer fitted with a Lurmark DT 30 flat spray nozzle.

The insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[5]), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®, 125/250 g a.i. L^{-1}, Du Pont de Nemours[6]) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle.

Thiram WP was applied to the seed as a fungicide coating at planting in the 2012/13 season at the rate of 150 g 100 kg^{-1} of seed (AG -Thiram 800 WP 800 g a.i. kg^{-1}).

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[1]The Edamame Development Program, PO Box 76355, Marbleray, 4037.

[2] Agricultural Research Council – Grain Crops Institute, P/Bag X1251, Potchefstroom, 2520.

[3] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[4] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

[5] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.

[6]Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

4.3.4 Data collection

Flowering date (R1) was determined when 50% of the plants in the centre two rows had at least one flower. The green pod harvest (R6) date occurred when the pods were green and the beans occupied 80 – 90% of the pod, with the lower leaves of the plants starting to turn yellow. A physiological maturity (R7) date was recorded when 90% of the pods had turned yellow. A maturity (R8) date was recorded when 95% of the pods had turned brown.

Due to the necessity to collect as many mature seeds as possible in the 2010/2011 season for future plantings, green pod and green bean yields were determined from six randomly selected plants in the centre two rows. In the subsequent seasons, starting 0.5 m from the beginning of the row, 1.5 m from each of the centre two rows were harvested. Mature seed yields were determined from the plants in the centre four meters of the two middle rows in the 2010/2011 season. In the subsequent seasons, mature yield was determined from 1.5 m of each of the centre two rows starting 0.5 m in from the end of each row. In the 2010/2011 season six harvested plants were used to determine the number of branches plant^{-1}, the percentages of seedless, 1-, 2- and 3-seeded pods and the shelling percentage. In the other seasons, 10 randomly selected plants were used to determine the number of branches plant^{-1}. All the pods from the net plot were used to determine the percentages of beans pod^{-1}, but a sub-sample of approximately 0.8 kg of green pods was used to determine shelling percentage. The number of plants in each net plot was counted at harvest. Pod and bean yields were weighed fresh, whilst the mature seed yields were converted to 12.5% moisture content. The moisture content was determined using a Sinar GrainPro 6310 Moisture Analyzer. One hundred randomly selected seeds were used to determine 100-seed mass. Plant height, measured from the ground to the top of the highest pod, and bottom pod height, measure from the ground to the bottom of the lowest pod, were done at maturity from eight randomly selected plants in the centre two rows. A 0.5 kg sample of green beans from each plot was submitted to the KZN DARD"s Analytical Services" Feed Laboratory for the determination of fat and crude protein content.

4.3.5 Statistical analysis

A randomized block design with three replicates was used. Each plot consisted of four rows, 5 m in length and spaced 0.75 m apart. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher"s Protected Least Significant Difference procedure with P=0.05.

4.4 RESULTS

4.4.1 Climatic conditions

The climatic conditions during each season had a significant effect on the performance of the cultivars. This resulted in significant interactions being measured between the seasons and cultivars for all the agronomic characteristics studied.

4.4.1.1 2010/11 season

The total rainfall received at Cedara during the 2010/2011 growing season was slightly lower than the 93 year mean (Table 4.1). January and especially February received considerably less rainfall than the long-term mean and the mean maximum and minimum temperatures during February and March were well above the 93 year mean for these two months (Tables 4.2 and 4.3).

From 84 to 93 days after planting (DAP) 1.0 mm of rain was recorded. This period coincided with flowering of the long-season cultivars. From 97 - 107 DAP another 1.0 mm of rain was received and the mean maximum temperature was 27.5°C. A further hot dry spell occurred from 111 to 128 DAP during which only 1.5 mm of rain was received. The mean maximum temperature during this period was 28.8°C. However, during the last 10 days of this period, the mean maximum temperature rose to 31.0°C. Fortunately 30.0 mm of rain fell between these two dry periods, which saved the crop.

4.4.1.2 2011/12 season

Well below-average rainfall was received at Cedara during the 2011/2012 growing season, particularly from February to April (Table 4.1). In addition, from January through to March warmer weather than the long-term mean was experienced (Tables 4.2 and 4.3). The yields of the longer-season cultivars were negatively affected by these conditions. However, the highest mean green bean yield was obtained in this season (Table 4.15.2).

4.4.1.3 2012/13 season

Total rainfall received at Cedara during the 2012/2013 growing-season was similar to the long-term mean (Table 4.1). The monthly maximum and minimum temperatures were warmer than the long-term mean in most of the months (Tables 4.2 and 4.3). Hail occurred on 24 December 2012, but little damage was caused. A severe hail and wind storm occurred on 31 December 2012 (49 DAP and 19 DAP for the first and second plantings, respectively). In the first planting considerable leaf loss and some lodging of the plants occurred. The short-season cultivars, AGS 292, AGS 329 and AGS 437, produced no new leaf growth after the storm. AGS 418, AGS 425 and AGS 440 produced some new leaf growth, whilst AGS 382 and AGS 423 produced more recovery leaf growth. The remaining cultivars were able to produce considerably more new leaf growth. Most of the above-mentioned cultivars were flowering at the time of the storm.

In the second planting the plant population was significantly reduced and 41% of the remaining plants had their main-stem broken off by the hail-storm that occurred on 31/12/2012. The plants were young at the time of the storm and were approximately 10 - 15 cm high. When the main-stem was broken off, the axillary buds on the highest node of the remaining main-stem developed as recovery "stems".

TABLE 4.1 Monthly rainfall recorded at Cedara during the three growing-seasons

Month	Season 2010/2011	2011/2012	2012/2013	Long-term mean*
	(mm)			
November	122	123	106	112
December	130	112	121	130
January	107	98	123	135
February	74	45	131	121
March	114	49	73	110
April	83	21	109	51
Total	**630**	**448**	**663**	**659**

* 93 years data (Source: ARC-ISCW). The figures highlighted in red and green indicate months with very low and high rainfall, respectively, when compared to the long-term mean.

TABLE 4.2 Monthly maximum temperatures recorded at Cedara during the three growing-seasons

Month	Season 2010/2011	2011/2012	2012/2013	Long-term mean*
	(mm)			
November	25.8	23.7	22.7	23.6
December	24.2	25.1	26.3	24.8
January	25.6	27.1	26.7	25.1
February	27.1	27.9	27.2	24.9
March	28.8	26.9	25.0	23.9
April	22.0	23.3	23.7	22.9

* 93 years data. The figures highlighted in red indicate when the monthly maximum temperatures were considerably higher than the long-term mean.

TABLE 4.3 Monthly minimum temperatures recorded at Cedara during the three growing-seasons

Month	2010/2011	Season 2011/2012	2012/2013 (mm)	Long-term mean*
November	12.6	11.8	12.3	12.4
December	13.7	14.2	14.9	12.6
January	15.3	15.7	15.3	13.6
February	15.3	16.1	14.8	13.5
March	15.2	13.2	14.0	11.9
April	10.3	8.6	9.6	10.6

* 93 years data. The figures highlighted in red indicate when the monthly minimum temperatures were considerably higher than the long-term mean.

4.4.2 Growth stages

4.4.2.1 Flowering

The number of days after planting (DAP) to 50% flowering varied significantly for the cultivars and seasons (Table 4.4.1). AGS 437 was the earliest to flower (45 days), whilst AGS 352, Lightning, Tanba and Tanbaguro took the longest mean DAP to 50% flowering (75 days) (Table 4.4.2). The seasonal mean DAP to 50% flowering was influenced by planting date. The earlier the planting date, the longer the cultivars took to reach 50% flowering.

TABLE 4.4.1 ANOVA table of days after planting to 50% flowering for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	2464.41	**	0.60	-
Season	2291.92	**	0.46	-
Cultivar x season	26.98	**	1.23	1.3

TABLE 4.4.2 Days after planting to 50% flowering for the various cultivars in the four trials

Cultivar	Season (DAP)				Mean
	2010/2011	2011/2012	2012/2013 (1st)	2012/2013 (2nd)	
AGS 437	51.3 a	42.0 a	46.3 a	42.0 ab	**45.3 a**
AGS 292	53.0 b	44.3 d	47.0 a	43.3 bc	**46.9 b**
AGS 329	53.0 b	44.3 d	47.0 a	42.0 ab	**46.6 b**
AGS 457	52.7 b	42.0 ab	49.3 b	42.0 ab	**46.6 b**
AGS 418	53.3 b	43.3 c	49.0 b	43.3 bc	**47.3 c**
AGS 440	53.0 b	43.0 bc	49.0 b	44.0 cd	**47.3 c**
AGS 458	55.3 c	46.7 e	52.0 cd	43.0 bc	**49.0 d**
AGS 423	57.0 d	46.7 e	49.0 b	45.3 de	**49.3 d**
AGS 382	58.0 de	47.0 f	51.3 c	46.3 ef	**50.7 e**
AGS 425	59.0 e	47.0 f	53.0 d	47.0 fg	**51.5 f**
AGS 353	64.3 f	51.0 g	60.0 ef	49.0 hi	**56.1 g**
AGS 354	64.3 f	51.0 g	59.7 e	48.3 gh	**55.8 g**
AGS 429	63.7 f	51.3 g	61.0 f	51.3 j	**56.8 h**
AGS 434	67.0 g	53.3 i	62.7 g	50.0 ij	**58.3 i**
AGS 335	67.7 g	52.0 h	60.3 ef	53.3 k	**58.3 i**
AGS 432	72.0 h	55.0 j	63.3 g	53.3 k	**60.9 j**
AGS 352	87.3 i	69.0 l	77.3 h	66.7 m	**75.1 k**
LIGHTNING	87.0 i	68.0 k	79.3 i	65.7 lm	**75.0 k**
TANBA	86.7 i	67.7 k	80.0 i	64.7 l	**74.8 k**
TANBAGURO	87.3 i	68.3 k	79.3 i	66.3 m	**75.3 k**
Mean	**64.7 a**	**51.6 c**	**58.8 b**	**50.3 d**	**56.3**
F value	5.52	0.67	0.00	2.15	26.98
P value	**	**	**	**	**
LSD (P<0.05)	1.09	0.94	1.16	1.62	1.23
CV %	1.0	1.1	1.2	1.9	1.3

4.4.2.2 Green pod harvest

The number of DAP to green pod harvest varied with the cultivars and seasons (Table 4.5). AGS 329 had the lowest mean DAP to green pod harvest (81 days), whilst AGS 352 and Lightning had the longest mean DAP to green pod harvest (125 days). The earlier planting dates in the 2010/11 and 2012/13 (1^{st}) seasons resulted in the cultivars taking longer to reach green pod harvest than in the other two seasons. Although planted earlier, the warmer temperatures may have contributed to the lower mean DAP to green pod harvest in the 2011/12 season than in the 2012/13 (2^{nd}) season.

TABLE 4.5 Days after planting to green pod harvest for the various cultivars in the four trials

Cultivar	**Season (DAP)**				**Mean**
	2010/2011	**2011/2012**	**2012/2013 (1^{st})**	**2012/2013 (2^{nd})**	
AGS 329	89	80	78	78	**81**
AGS 292	89	81	79	78	**82**
AGS 437	97	86	85	92	**90**
AGS 440	101	86	91	92	**93**
AGS 457	102	86	95	92	**93**
AGS 382	102	87	95	93	**94**
AGS 418	101	86	95	92	**94**
AGS 425	104	87	95	93	**95**
AGS 458	105	86	101	92	**96**
AGS 423	108	92	101	93	**99**
AGS 335	111	95	109	97	**103**
AGS 434	115	100	109	97	**105**
AGS 354	115	100	109	97	**105**
AGS 353	117	100	109	97	**106**
AGS 429	117	100	109	97	**106**
AGS 432	119	100	109	100	**107**
TANBA	126	114	130	116	**122**
TANBAGURO	126	114	130	116	**122**
AGS 352	138	114	133	116	**125**
LIGHTNING	135	114	133	116	**125**
Mean	**111**	**96**	**106**	**98**	**103**

(Note: There was no variation in harvest date between the replicates in all four plantings and with every cultivar. Therefore no statistical analysis could be done.)

4.4.2.3 Physiological maturity

The number of DAP to physiological maturity varied significantly for the cultivars and seasons (Table 4.6.1). AGS 292 and AGS 329 had the lowest mean DAP to physiological maturity (95 days), whilst AGS 352 had the longest mean DAP to physiological maturity (139 days) (Table 4.6.2). The later planting dates in the 2011/12 and 2012/13 (2nd) seasons resulted in the cultivars reaching physiological maturity earlier. Although planted earlier, the lower mean DAP to physiological maturity may have been due to the warmer temperatures experienced in the 2011/12 season than in the 2012/13 (2nd) season.

TABLE 4.6.1 ANOVA table of days after planting to physiological maturity for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	2488.09	**	0.81	-
Season	1724.07	**	0.71	-
Cultivar x season	26.63	**	1.69	0.9

TABLE 4.6.2 Days after planting to physiological maturity for the various cultivars in the four seasons

			Season		
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st) (DAP)**	**2012/2013 (2nd)**	**Mean**
AGS 292	105.0 b	89.0 a	94.3 a	91.3 a	**94.9 a**
AGS 329	104.0 a	89.0 a	94.7 a	90.7 a	**94.6 a**
AGS 437	106.0 c	92.0 b	104.3 b	97.3 b	**99.9 b**
AGS 440	111.0 e	92.0 b	106.3 cd	97.3 b	**101.7 c**
AGS 457	110.0 d	90.7 ab	105.7 bc	97.3 b	**100.9 c**
AGS 458	112.7 f	92.0 b	112.3 e	97.7 b	**103.7 d**
AGS 382	112.3 f	99.3 e	108.0 d	101.7 c	**105.3 e**
AGS 418	114.0 g	94.0 c	111.7 e	99.0 b	**104.7 e**
AGS 425	119.0 h	96.7 d	111.0 e	102.0 c	**107.2 f**
AGS 423	120.0 i	100.7 ef	119.3 f	106.0 d	**111.5 g**
AGS 335	120.0 i	101.7 f	120.0 f	111.0 f	**113.2 h**
AGS 434	125.0 j	110.0 gh	122.3 g	108.3 e	**116.4 i**
AGS 353	125.0 j	108.3 g	127.7 h	110.7 f	**117.9 j**
AGS 354	126.0 k	108.3 g	127.0 h	111.0 f	**118.1 j**
AGS 429	126.0 k	112.3 i	128.7 h	113.0 g	**120.0 k**
AGS 432	131.0 l	110.7 hi	127.7 h	114.3 g	**120.9 l**
LIGHTNING	145.0 m	122.7 j	147.7 i	129.7 h	**136.2 m**
TANBAGURO	145.0 m	123.0 j	149.7 j	132.7 i	**137.6 n**
TANBA	145.0 m	123.0 j	150.7 j	131.7 i	**137.6 n**
AGS 352	146.3 n	127.0 k	150.3 j	132.3 i	**139.0 o**
Mean	**122.4 a**	**104.1 d**	**121.0 b**	**108.8 c**	**114.1**
F value	0.32	1.82	6.77	0.04	26.63
P value	**	**	**	**	**
LSD (P<0.05)	0.75	1.82	1.91	1.84	1.69
CV %	0.4	1.1	1.0	1.0	0.9

4.2.2.4 Harvest maturity

The number of DAP to harvest maturity varied significantly for the cultivars and seasons (Table 4.7.1). AGS 292 and AGS 329 had the lowest mean DAP to harvest maturity (101 days), whilst AGS 352 had the longest mean DAP to harvest maturity (147 days) (Table 4.7.2). The earlier the planting date, the longer the cultivars took to reach harvest maturity. However, the warmer temperatures experienced during the 2011/12 season may have contributed to the lower mean DAP to harvest maturity than that recorded in the 2012/13 (2nd) season.

TABLE 4.7.1 ANOVA table of days after planting to harvest maturity for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	984.40	**	1.33	-
Season	566.38	**	1.27	-
Cultivar x season	12.22	**	2.81	1.4

TABLE 4.7.2 Days after planting (DAP) to harvest maturity for the various cultivars in the four trials

	Season				
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st) (DAP)**	**2012/2013 (2nd)**	**Mean**
AGS 292	112.0 a	93.7 a	102.0 a	98.0 a	**101.4 a**
AGS 329	112.0 a	93.0 a	102.7 a	97.3 a	**101.2 a**
AGS 457	117.0 b	94.3 ab	110.0 b	102.0 b	**105.8 b**
AGS 440	117.0 b	97.7 bc	111.3 b	103.0 bc	**107.2 c**
AGS 437	117.0 b	99.7 c	109.0 b	105.7 de	**107.8 c**
AGS 458	122.0 d	96.7 abc	117.3 d	104.7 cd	**110.2 d**
AGS 382	121.0 c	108.0 d	114.3 c	108.3 fg	**112.9 e**
AGS 418	121.0 c	105.0 d	117.3 d	107.7 ef	**112.8 e**
AGS 425	124.0 e	105.3 d	117.7 d	110.3 gh	**114.3 f**
AGS 423	126.7 f	112.3 e	126.3 e	112.0 h	**119.3 g**
AGS 335	124.0 e	112.3 e	125.7 e	118.3 ij	**120.1 gh**
AGS 434	128.0 g	114.0 ef	127.3 e	116.0 i	**121.3 h**
AGS 353	130.0 h	112.7 e	130.3 f	118.7 j	**122.9 i**
AGS 354	131.0 i	112.7 e	130.0 f	117.7 ij	**122.8 i**
AGS 429	132.0 j	117.0 f	136.0 g	123.0 k	**127.0 j**
AGS 432	137.0 k	116.0 ef	136.3 g	123.0 k	**128.1 j**
LIGHTNING	156.0 l	128.7 g	153.0 h	135.0 l	**143.2 k**
TANBA	161.0 n	130.7 gh	157.3 i	137.3 lm	**146.6 l**
TANBAGURO	161.0 n	131.0 gh	155.7 i	138.0 m	**146.4 l**
AGS 352	159.0 m	133.0 h	157.3 i	137.3 lm	**146.7 l**
Mean	**130.4 a**	**110.7 d**	**126.9 b**	**115.7 c**	**120.9**
F value	1.69	4.86	2.66	0.85	12.22
P value	**	**	**	**	**
LSD (P<0.05)	0.91	3.96	2.40	2.67	2.81
CV %	0.4	2.2	1.1	1.4	1.4

4.4.3 Plant population

All the cultivars were planted at a seeding rate of 266 667 seeds ha^{-1}. However, plant population ha^{-1} at harvest varied among the cultivars in all the seasons (Tables 4.8.1 and 4.8.2), resulting in a significant interaction being measured between the cultivars and seasons. No significant difference in mean plant population ha^{-1} was measured in the 2010/11 and 2011/12 seasons, but significant differences were measured between the cultivars. AGS 292, AGS 329 and AGS 352 had low plant populations in the 2010/11 season, whilst AGS 434 and AGS 382 had low plant populations in the 2012/13 season, due to poor seed quality. Low plant populations were recorded in all four seasons for AGS 440. Overall, plant population as a percentage of seeding rate was 57.3% and 59.2% for the 2010/11 and 2011/12 seasons, respectively.

Both plantings in the 2012/13 season had significantly higher mean plant populations than in the 2010/11 and 2011/12 seasons. Mean plant population ha^{-1} was 79.7% and 70.4% of the seeding rate for the first and second plantings of the 2012/13 season, respectively. Thiram, which was applied as a fungicide seed coating at planting in the 2012/13 season, but not in the 2010/11 and 2011/12 seasons, may have contributed to the higher plant populations in the 2012/13 season. The hail storm on 31/12/2012 destroyed some plants, which resulted in a significantly lower mean plant population in the 2012/13 (2^{nd}) season.

Plant population ha^{-1} had significant positive correlations with green pod and green bean yields, plant height and bottom pod height, but significant negative correlations with 100-seed mass, number of pods $plant^{-1}$ and percentage export marketable pods (Table 4.19).

TABLE 4.8.1 ANOVA table of plant population for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	31.83	**	15.3	-
Season	64.06	**	11.4	-
Cultivar x season	12.38	**	31.4	10.7

TABLE 4.8.2 Plant population recorded for the various cultivars during the four seasons

Cultivar	Season 2010/2011	2011/2012	2012/2013 (1st) (plants ha^{-1} x 1000)	2012/2013 (2nd)	Mean
AGS 440	116.9	83.2	77.0	83.0	**90.0[2]**
AGS 434	157.8	41.9[1]	207.4	171.9	**144.7**
AGS 418	163.1	105.0	204.4	140.7	**153.3**
AGS 429	144.4	113.3	205.9	152.6	**154.1**
AGS 437	160.4	191.1	143.7	125.9	**155.3**
AGS 382	163.6	93.3[1]	201.5	200.0	**164.6**
AGS 423	137.3	113.3	228.2	183.7	**165.6**
AGS 432	171.6	142.2	220.7	158.5	**173.3**
AGS 353	163.1	100.0	235.6	208.9	**176.9**
AGS 292	71.6[1]	215.6	237.0	204.4	**182.2**
AGS 425	165.8	153.3	216.3	194.1	**182.4**
AGS 352	79.6[1]	220.0	220.7	216.3	**184.2**
AGS 329	83.1[1]	226.7	222.2	208.9	**185.2**
TANBAGURO	159.1	164.4	228.2	210.4	**190.5**
AGS 335	180.0	173.3	226.7	198.5	**194.6**
TANBA	179.6	173.3	217.8	210.4	**195.3**
AGS 354	196.0	117.8	253.3	238.5	**201.4**
LIGHTNING	188.4	197.8	240.0	220.7	**211.7[3]**
AGS 458	184.0	268.9	222.2	200.0	**218.8[3]**
AGS 457	192.0	262.2	253.3	226.7	**233.6[3]**
Mean	**152.9 c**	**157.8 c**	**213.1 a**	**187.7 b**	**177.9**
F value	24.23	22.23	17.13	9.59	12.38
P value	**	**	**	**	**
LSD (P<0.05)	21.7	38.42	27.31	35.49	31.4
CV %	8.6	14.4	7.8	11.4	10.7

The figures highlighted in red and green indicate low and high plant population.
[1]Poor seed storage or quality affected germination and emergence
[2]Poor germinator
[3]Exceptional germinator

4.4.4 Plant height and bottom pod height

A significant interaction was measured between the cultivars and seasons for plant height (Tables 4.9.1). Mean plant heights were significantly lower in both plantings of the 2012/13 season than in the 2010/11 and 2011/12 seasons due to the effects of the hailstorm (Table 4.9.2).

Significant positive correlations were measured between plant height and green pod yield, green bean yield, plant population, bottom pod height, number of pods plant^{-1}, percentage crude protein and percentage fat (Table 4.19). Negative, but insignificant, correlations were measured between plant height and percentage export marketable pods and 100-seed mass.

A significant interaction was measured between the cultivars and seasons for bottom pod height (Table 4.10.1). Mean bottom pod height was significantly lower in the 2012/13 season (2nd) than in the other seasons (Table 4.10.2). As cultivar growing-season length increased, plant height and bottom pod height increased.

Significant positive correlations were measured between bottom pod height and green pod yield, green bean yield, plant population, plant height, percentage crude protein and percentage fat (Table 4.19). A significant negative correlation was measured between bottom pod height and percentage export marketable pods.

TABLE 4.9.1 ANOVA table of plant height for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	256.47	**	3.3	-
Season	68.70	**	3.1	-
Cultivar x season	8.75	**	6.9	6.3

TABLE 4.9.2 Plant height recorded for the various cultivars in the four seasons

Cultivar	**2010/2011**	**2011/2012**	**Season 2012/2013 (1st) (cm)**	**2012/2013 (2nd)**	**Mean**
AGS 329	29.3	51.1	31.8	33.6	**36.5**
AGS 292	31.2	51.1	35.5	34.7	**38.1**
AGS 437	47.1	57.4	38.8	37.1	**45.1**
AGS 440	52.1	56.9	39.9	38.3	**46.8**
AGS 382	59.4	49.0	41.6	45.4	**48.9**
AGS 425	58.4	57.9	47.0	39.8	**50.8**
AGS 418	64.9	44.2	50.8	46.4	**51.6**
AGS 457	60.2	61.4	40.2	46.7	**52.2**
AGS 423	70.8	47.6	50.9	49.4	**54.7**
AGS 458	68.9	66.3	46.3	49.2	**57.7**
AGS 354	72.5	62.5	56.6	66.2	**64.4**
AGS 353	71.4	62.4	59.1	67.1	**65.0**
AGS 335	78.8	69.9	59.8	65.4	**68.5**
AGS 432	89.4	66.1	62.9	64.1	**70.6**
AGS 429	90.2	69.2	65.8	62.1	**71.8**
AGS 434	104.8	85.7	68.3	70.7	**82.4**
AGS 352	84.2	93.6	80.1	82.9	**85.2**
TANBAGURO	108.9	95.4	90.6	82.4	**94.3**
LIGHTNING	108.9	96.5	91.5	81.8	**94.7**
TANBA	110.9	95.9	88.5	84.0	**94.8**
Mean	**73.1 a**	**67.0 b**	**57.3 c**	**57.4 c**	**63.7**
F value	258.74	49.25	49.98	46.17	8.75
P value	**	**	**	**	**
LSD (P<0.05)	4.32	7.03	7.56	7.32	6.90
CV %	3.6	6.4	8.0	7.7	6.3

TABLE 4.10.1 ANOVA table of bottom pod height for the cultivars and seasons for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Cultivar	72.77	**	1.8	-
Season	16.52	**	1.4	-
Cultivar x season	8.59	**	3.7	14.2

TABLE 4.10.2 Bottom pod height recorded for the various cultivars in the four seasons

Cultivar	**2010/2011**	**2011/2012**	**Season** **2012/2013 (1st)** **(cm)**	**2012/2013 (2nd)**	**Mean**
AGS 437	4.5	10.6	7.8	7.0	**7.5**
AGS 440	8.4	7.0	9.4	6.7	**7.9**
AGS 292	2.0	12.2	11.1	10.1	**8.8**
AGS 329	2.9	11.7	10.6	10.6	**9.0**
AGS 382	12.5	10.8	11.0	14.9	**12.3**
AGS 429	13.6	8.3	17.7	10.1	**12.4**
AGS 457	12.4	13.2	13.0	12.5	**12.8**
AGS 418	12.9	14.5	13.6	12.9	**13.5**
AGS 423	18.2	9.3	16.4	13.5	**14.3**
AGS 425	20.6	14.2	14.6	9.6	**14.8**
AGS 354	22.2	9.6	17.7	13.4	**15.7**
AGS 353	18.7	11.1	22.0	12.7	**16.1**
AGS 458	20.2	19.9	12.9	11.7	**16.2**
AGS 432	22.1	13.4	20.2	14.5	**17.5**
LIGHTNING	22.4	18.7	19.0	17.5	**19.4**
AGS 335	24.1	19.5	23.5	15.8	**20.7**
AGS 434	26.2	20.8	22.9	15.3	**21.3**
AGS 352	21.7	30.0	17.7	18.2	**21.9**
TANBAGURO	33.2	21.9	22.1	22.7	**25.0**
TANBA	32.6	26.3	23.8	21.9	**26.2**
Mean	**17.6 a**	**15.1 b**	**16.3 ab**	**13.6 c**	**15.7**
F value	28.52	23.75	19.21	20.99	8.59
P value	**	**	**	**	**
LSD (P<0.05)	4.75	3.70	3.30	2.67	3.7
CV %	16.3	15.0	12.2	11.9	14.2

4.4.5 Export marketable pods*

A significant interaction with the cultivars and seasons was measured for percentage export marketable pods (Table 4.11.1). Despite the drier and warmer conditions, a significantly higher mean percentage export marketable pods was produced in the 2011/12 season than in the other seasons (Table 4.11.2). Tanba, AGS 437 and Tanbaguro produced the lowest mean percentages of export marketable pods (< 58%), whilst AGS 425 and AGS 429 produced the highest mean percentages of export marketable pods (≥ 76%).

Significant positive correlations were measured between percentage export marketable pods and green bean yield and the number of pods $plant^{-1}$ (Table 4.19). Significant negative correlations were measured between percentage export marketable pods and plant population, bottom pod height, 100-seed mass and percentage crude protein.

*Export marketable pods are pods containing two or more beans. The length and width of the pods have not been considered, although they are important charcteristics to meet the requirements of the export market.

TABLE 4.11.1 ANOVA table of the percentage export marketable pods (≥ 2 beans pod^{-1}) for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	22.95	**	3.5	-
Season	41.78	**	2.4	-
Cultivar x season	4.36	**	7.1	6.3

TABLE 4.11.2 Export marketable pods (≥ 2 beans pod^{-1}) recorded for the various cultivars in the four seasons

Cultivar	2010/2011	2011/2012	Season 2012/2013 (1st) (%)	2012/2013 (2nd)	Mean
TANBA	52.4	56.0	55.6	61.1	**56.3**[1]
AGS 437	48.8	66.4	59.0	56.6	**57.7**[1]
TANBAGURO	55.2	58.7	56.1	61.2	**57.8**[1]
AGS 329	46.8	79.7	66.0	62.8	**63.8**
AGS 292	51.3	79.8	64.8	66.4	**65.6**
AGS 432	65.0	66.6	63.4	69.2	**66.0**
AGS 382	55.4	82.1	64.5	67.6	**67.4**
AGS 457	60.2	74.9	68.0	71.6	**68.7**
AGS 353	68.7	75.8	65.9	66.7	**69.2**
AGS 354	66.6	76.8	68.4	64.9	**69.2**
LIGHTNING	66.9	74.1	67.4	75.4	**71.0**
AGS 352	70.5	69.5	71.3	74.4	**71.4**
AGS 423	79.3	77.6	64.3	68.8	**72.5**
AGS 335	68.2	81.9	73.2	67.2	**72.6**
AGS 434	69.9	80.2	69.5	70.7	**72.6**
AGS 458	67.2	76.5	71.2	77.5	**73.1**
AGS 418	69.1	86.2	62.7	75.0	**73.3**
AGS 440	73.6	82.4	67.2	72.1	**73.8**
AGS 429	73.5	78.0	74.7	77.8	**76.0**[2]
AGS 425	82.3	82.3	71.7	71.4	**76.9**[2]
Mean	**64.5 c**	**75.3 a**	**66.2 c**	**68.9 b**	**68.7**
F value	11.05	10.21	5.12	7.74	4.36
P value	**	**	**	**	**
LSD (P<0.05)	8.62	7.22	6.61	5.93	7.1
CV %	8.1	5.8	6.0	5.2	6.3

[1]Producer of low percentage of export marketable pods

[2]Producer of high percentage of export marketable pods

The figures highlighted in red and green indicate cultivars with low and high percentages of export marketable pods.

4.4.6 Number of pods per plant

A significant interaction with the cultivars and seasons was measured for number of pods plant^{-1} (Table 4.12.1). The mean number of pods plant^{-1} was significantly higher in the 2011/12 season than in the other seasons, among which there were no significant differences (Table 4.12.2). The mean number of pods plant^{-1} ranged from 14.8 (AGS 425) to 36.5 (AGS 352). Lightning and AGS 457 produced a consistently high and low number of pods plant^{-1} in all four seasons, respectively. Low plant populations resulted in AGS 352, and AGS 434 and AGS 353 producing significantly high numbers of pods plant^{-1} in the 2010/11 and 2011/12 seasons, respectively.

Significant positive correlations were measured between the number of pods plant^{-1} and green pod yield, green bean yield, plant height, percentage export marketable pods and percentage fat (Table 4.19). Significant negative correlations were measured between the number of pods plant^{-1} and plant population and 100-seed mass.

TABLE 4.12.1 ANOVA table of the pods with beans plant^{-1} for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	32.14	**	3.05	-
Season	18.10	**	3.16	-
Cultivar x season	11.22	**	6.55	17.3

TABLE 4.12.2 Pods with beans plant^{-1} recorded for the various cultivars in the four seasons

Cultivar	Season (number plant^{-1}) 2010/2011	2011/2012	2012/2013 (1st)	2012/2013 (2nd)	Mean
AGS 425	8.6	21.3	14.5	14.9	**14.8**
AGS 335	12.5	18.3	15.8	16.7	**15.8**
AGS 457	15.0	16.0	15.8	16.5	**15.8**[2]
AGS 458	14.8	14.3	17.9	19.6	**16.7**
AGS 329	17.0	16.5	14.4	19.1	**16.8**
AGS 437	11.3	18.4	15.3	23.5	**17.1**
AGS 292	20.9	17.5	14.6	16.9	**17.5**
TANBA	20.9	18.5	15.4	16.0	**17.7**
TANBAGURO	23.2	21.5	14.2	16.8	**18.9**
AGS 418	11.0	29.1	18.3	21.1	**19.9**
AGS 382	15.2	32.5	16.7	17.4	**20.4**
AGS 354	16.5	37.8	16.7	19.1	**22.5**
AGS 432	21.8	26.1	18.6	24.8	**22.8**
AGS 423	17.6	36.2	18.5	21.7	**23.5**
AGS 440	15.4	29.9	25.3	24.7	**23.8**
AGS 429	20.1	35.0	20.3	23.7	**24.8**
AGS 353	19.4	45.5	20.2	19.4	**26.1**
LIGHTNING	32.8	30.7	32.0	32.2	**31.9**[1]
AGS 434	21.7	66.1	23.3	22.1	**33.3**
AGS 352	58.0	27.3	32.7	27.9	**36.5**
Mean	**19.7 b**	**27.9 a**	**19.0 b**	**20.7 b**	**21.8**
F value	36.29	13.76	12.70	6.58	11.22
P value	**	**	**	**	**
LSD (P<0.05)	4.99	9.63	4.37	4.96	6.55
CV %	15.3	20.8	13.9	14.5	17.3

[1]Lightning produced a consistently high number of pods plant^{-1} over the four seasons.
[2]AGS 457 produced a consistently low number of pods plant^{-1} over the four seasons.
The figures highlighted in red and green indicate cultivars with very low and high numbers of pods plant^{-1}, respectively.

4.4.7 Seed mass

A significant interaction between the cultivars and seasons was measured for 100-seed mass (Table 4.13.1). Mean 100-seed mass was significantly higher in the 2010/11 season, but significantly lower in the 2011/12 season than in the other three seasons (Table 4.13.2). Lightning and AGS 352 produced significantly lower mean 100-seed masses than the other cultivars (< 27 g), which is below the export market requirement of ≥ 30 g per 100 seeds (dry). AGS 440, Tanba and Tanbaguro produced the highest 100-seed masses (> 45 g).

Significant negative correlations were measured between 100-seed mass and green pod yield, green bean yield, plant population, percentage export marketable pods and number of pods plant^{-1} (Table 4.19). A significant positive correlation was measured between 100-seed mass and percentage crude protein.

TABLE 4.13.1 ANOVA table of the 100-seed mass for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	124.96	**	1.39	-
Season	21.70	**	1.47	-
Cultivar x season	14.00	**	3.00	4.4

TABLE 4.13.2 100-seed mass recorded for the various cultivars in the four seasons

	Season				
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st)**	**2012/2013 (2nd)**	**Mean**
			(g)		
LIGHTNING	24.5	24.2	30.0	27.0	**26.4**[1]
AGS 352	21.8	26.8	30.8	27.7	**26.8**[1]
AGS 457	37.3	34.2	35.2	34.2	**35.2**
AGS 434	39.2	32.9	33.5	36.7	**35.6**
AGS 458	38.7	31.8	37.0	35.2	**35.7**
AGS 329	45.3	36.3	33.3	34.0	**37.4**
AGS 292	46.7	36.2	33.5	33.8	**37.5**
AGS 335	39.7	34.8	38.7	36.8	**37.5**
AGS 353	46.0	34.5	36.8	43.0	**40.1**
AGS 354	45.8	33.0	37.3	44.7	**40.2**
AGS 423	46.7	36.3	40.2	38.5	**40.4**
AGS 429	43.2	38.7	41.3	39.8	**40.8**
AGS 382	39.5	40.7	41.0	42.3	**40.9**
AGS 437	46.2	39.0	42.5	40.2	**42.0**
AGS 425	49.8	38.8	39.7	41.7	**42.5**
AGS 432	43.5	40.0	45.5	42.0	**42.8**
AGS 418	50.2	39.9	42.3	41.3	**43.4**
TANBAGURO	39.7	44.3	50.7	48.0	**45.7**[2]
TANBA	37.8	43.2	53.5	50.3	**46.2**[2]
AGS 440	52.2	45.9	46.5	46.3	**47.7**[2]
Mean	**41.7 a**	**36.6 c**	**39.5 b**	**39.2 b**	**39.2**
F value	55.90	59.03	22.86	59.61	14.00
P value	**	**	**	**	**
LSD (P<0.05)	2.95	2.06	3.73	2.28	3.00
CV %	4.3	3.4	5.7	3.5	4.4

[1] Small-seeded cultivar. [2] Large-seeded cultivar.
The figures highlighted in red and green indicate cultivars with very low and high 100-seed masses, respectively.

4.4.8 Yield

4.4.8.1 Green pod yield

A significant interaction between the cultivars and seasons was measured for green pod yield (Table 4.14.1). Mean green pod yield was significantly lower in the 2010/11 season than in the other three seasons, among which there were no significant differences (Table 4.14.2). AGS 440 produced the lowest mean green pod yield (7.4 t ha^{-1}), due to consistently low plant populations. Lightning produced the highest mean green pod yield (12 t ha^{-1}), due to consistently high yields in all four seasons. The short-season cultivars, AGS 292 and AGS 329, produced low yields in the 2010/11 season, due to low plant populations, but recorded significantly higher yields in the 2011/12 season when the plant populations were significantly higher.

Significant positive correlations were measured between green pod yield and green bean yield, plant population, plant height, bottom pod height, number of pods $plant^{-1}$ and percentage fat (Table 4.19). A significant negative correlation was measured between green pod yield and 100-seed mass.

TABLE 4.14.1 ANOVA table of the green pod yield for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	14.39	**	947.8	-
Season	6.65	*	553.9	-
Cultivar x season	5.04	**	1906.7	12.1

TABLE 4.14.2 Green pod yield recorded for the various cultivars in the four seasons

Cultivar			**Season**		
	2010/2011	**2011/2012**	**2012/2013 (1st)**	**2012/2013 (2nd)**	**Mean**
			(kg ha^{-1})		
AGS 440	6 738	8 196	6 123	8 380	**7 359**[1]
AGS 437	5 609	9 974	6 148	8 326	**7 515**
AGS 292	4 265	11 200	7 451	8 452	**7 842**
AGS 329	4 506	10 512	7 258	9 636	**7 978**
AGS 425	5 988	9 218	8 555	8 750	**8 128**
AGS 382	7 413	9 300	10 210	10 553	**9 369**
AGS 418	7 612	10 351	10 930	9 691	**9 646**
AGS 429	11 247	8 787	9 627	9 569	**9 807**
AGS 335	8 569	9 430	11 919	9 456	**9 843**
AGS 434	10 784	8 973	11 024	10 025	**10 202**
AGS 458	9 192	9 431	10 546	11 356	**10 131**
AGS 423	10 370	10 913	9 477	10 164	**10 231**
TANBA	12 532	8 559	9 170	11 219	**10 370**
AGS 457	9 133	11 692	10 818	10 378	**10 505**
TANBAGURO	13 157	9 335	8 481	11 149	**10 531**
AGS 352	8 709	9 841	12 615	11 243	**10 602**
AGS 354	10 179	10 050	10 449	11 842	**10 630**
AGS 432	12 044	9 885	10 427	10 560	**10 729**
AGS 353	11 764	10 421	10 593	10 605	**10 846**
LIGHTNING	12 931	9 970	12 753	12 625	**12 070**[2]
Mean	**9 137 b**	**9 802 a**	**9 729 a**	**10 199 a**	**9 717**
F value	13.74	1.81	11.40	4.80	5.04
P value	**	NS	**	**	**
LSD (P<0.05)	2 143	1895.3	1624.0	1055.6	1906.7
CV %	14.2	11.7	10.1	12.7	12.1

[1]Low producer due to low plant stands.
[2]Consistently high producer.
The figures highlighted in red and green indicate cultivars with very low and high yields, respectively.

4.4.8.2 Green bean yield

A significant interaction between the cultivars and seasons was measured for green bean yield (Table 4.15.1). Mean green bean yield was significantly higher in the 2011/12 season than in the 2010/11 and 2012/13 (1st) seasons (Table 4.15.2). The hailstorm may have caused the significantly low mean green bean yield in the 2012/13 (1st) season. AGS 292 produced the lowest mean green bean yield (3.6 t ha^{-1}), whilst Lightning produced the highest green bean yield 6.7 t ha^{-1}).

Significant positive correlations were measured between green bean yield and green pod yield, plant population, plant height, bottom pod height, percentage export marketable pods, number of pods plant^{-1} and percentage fat (Table 4.19). A significant negative correlation was measured between green bean yield and 100-seed mass.

TABLE 4.15.1 ANOVA table of the green bean yield for the various cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	19.22	**	514.7	-
Season	12.91	**	256.2	-
Cultivar x season	4.90	**	1 026.6	12.9

TABLE 4.15.2 Green bean yield recorded for the various cultivars in the four seasons

Cultivar	Season (kg ha^{-1}) 2010/2011	2011/2012	2012/2013 (1st)	2012/2013 (2nd)	Mean
AGS 292	1 997	5 629	3 150	3 713	**3 622**
AGS 437	2 851	5 151	2 574	4 044	**3 655**
AGS 329	2 122	5 405	2 996	4 234	**3 690**
AGS 440	4 062	4 521	2 976	4 132	**3 923**
AGS 425	3 399	4 784	4 214	4 440	**4 209**
AGS 335	3 921	4 962	5 460	3 976	**4 580**
AGS 382	4 232	4 765	5 051	5 254	**4 826**
AGS 434	5 608	4 629	4 868	4 493	**4 899**
AGS 429	6 213	4 622	4 277	4 494	**4 902**
AGS 418	4 436	5 657	5 223	4 664	**4 995**
AGS 458	4 736	4 914	4 971	5 631	**5 063**
AGS 423	5 593	5 900	4 427	4 986	**5 226**
AGS 432	6 790	4 970	4 350	5 419	**5 382**
AGS 352	4 583	5 338	6 234	5 472	**5 407**
AGS 457	4 898	6 193	5 178	5 478	**5 437**
TANBA	6 505	4 902	4 709	5 888	**5 501**
TANBAGURO	6 963	5 402	4 299	5 715	**5 595**
AGS 354	5 924	5 641	4 862	6 188	**5 654**
AGS 353	6 927	5 913	4 945	5 453	**5 809**
LIGHTNING	7 086	6 052	6 912	6 582	**6 658**
Mean	**4 942 b**	**5 268 a**	**4 584 c**	**5 013 ab**	**4 952**
F value	13.03	1.97	15.00	4.80	4.90
P value	**	*	**	**	**
LSD (P<0.05)	1 261.2	1057.3	794.2	1055.6	1026.6
CV %	15.4	12.1	10.5	12.7	12.9

4.4.9 Crude protein and fat

Significant interactions with the cultivars and seasons were measured for crude protein and fat content (Tables 4.16 and 4.17). Mean crude protein content was significantly higher in both plantings in the 2012/13 season than in the 2010/11 and 2011/12 seasons, between which there were no significant differences (Table 4.18). Mean crude protein ranged from 41.1% (AGS 418) to 44.5% (AGS 335). Mean crude protein and fat contents were lowest in the 2010/11 season. Mean fat content was significantly higher in the 2012/13 (2^{nd}) season than in the other three seasons. Mean fat content ranged from 15.4% (AGS 437) to 19.2% (AGS 352). The longer-season cultivars tended to produce higher percentages of fat.

A significant negative correlation was measured between percentage crude protein and percentage export marketable pods (Table 4.19). Significant positive correlations were measured between percentage crude protein and plant height, bottom pod height, 100-seed mass and percentage fat.

Significant positive correlations were measured between percentage fat and green pod and green bean yields, plant height, bottom pod height, number of pods $plant^{-1}$ and crude protein (Table 4.19). No significant negative correlations were measured.

TABLE 4.16 ANOVA table of the crude protein percentage for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	12.14	**	0.78	-
Season	21.32	**	0.54	-
Cultivar x season	7.82	**	1.59	2.3

TABLE 4.17 ANOVA table of the fat percentage for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	13.62	**	0.81	-
Season	130.73	**	0.32	-
Cultivar x season	4.89	**	1.60	5.9

The number of branches $plant^{-1}$, percentage seedless pods, percentage 1-seeded pods, shelling percentage and seed yield were measured and appear in the Appendix (Page 277).

TABLE 4.18 Crude protein and fat content on a dry matter basis recorded for the various cultivars in the four seasons

	Crude protein Season					Fat Season				
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st) (%)**	**2012/2013 (2nd)**	**Mean**	**2010/2011**	**2011/2012**	**2012/2013 (1st) (%)**	**2012/2013 (2nd)**	**Mean**
AGS 418	40.8	40.5	42.1	41.0	**41.1**	13.6	15.0	17.6	17.5	**15.9**
AGS 292	43.2	37.7	43.5	40.4	**41.2**	16.1	18.3	17.4	17.3	**17.3**
AGS 458	41.3	40.2	42.3	41.2	**41.2**	15.1	15.9	16.6	16.8	**16.1**
AGS 353	40.2	42.2	41.4	42.8	**41.7**	16.8	15.7	17.7	20.9	**17.8**
AGS 354	41.2	42.0	40.8	43.0	**41.8**	16.8	17.8	18.0	21.5	**18.5**
AGS 457	43.2	41.0	40.9	42.4	**41.9**	14.5	15.3	18.0	15.7	**15.9**
AGS 329	42.4	40.7	43.6	41.2	**42.0**	15.3	17.3	16.6	16.4	**16.4**
AGS 425	41.3	41.6	42.6	43.7	**42.3**	15.5	16.2	16.6	18.4	**16.7**
AGS 352	40.9	43.8	43.9	41.2	**42.5**	19.1	19.0	19.4	19.1	**19.2**
AGS 432	40.2	42.4	42.4	45.3	**42.6**	14.4	18.1	15.5	18.6	**16.6**
AGS 382	42.9	41.8	43.2	43.0	**42.7**	12.9	17.1	16.2	17.6	**16.0**
AGS 423	42.3	42.4	42.5	43.5	**42.7**	14.8	17.3	16.7	17.6	**16.6**
AGS 429	40.5	42.3	42.8	45.6	**42.8**	15.9	19.2	15.7	19.2	**17.5**
AGS 440	43.3	42.3	42.8	44.2	**43.2**	13.8	19.2	14.5	16.2	**16.0**
TANBA	39.1	44.6	46.8	42.5	**43.2**	14.3	18.5	20.1	18.3	**17.8**
AGS 434	40.9	43.8	42.6	45.7	**43.3**	16.8	18.8	15.3	18.9	**17.4**
TANBAGURO	40.2	44.3	46.1	43.2	**43.4**	14.4	18.9	18.9	18.8	**17.7**
LIGHTNING	41.3	43.7	45.9	43.9	**43.7**	18.3	19.5	18.6	18.6	**18.8**
AGS 437	46.6	41.8	43.9	44.5	**44.2**	15.3	17.2	13.8	15.5	**15.4**
AGS 335	43.0	44.2	44.4	46.5	**44.5**	14.8	15.9	16.1	18.2	**16.2**
Mean	**41.7 b**	**42.2 b**	**43.2 a**	**43.2 a**	**42.6**	**15.4 d**	**17.5 b**	**17.0 c**	**18.1 a**	**17.0**
F value	10.78	7.61	6.75	12.02	7.82	10.46	3.33	7.86	13.59	4.89
P value	**	**	**	**	**	**	**	**	**	**
LSD (P<0.05)	1.45	1.73	1.78	1.43	1.59	1.38	2.27	1.66	1.19	1.60
CV %	2.1	2.5	2.5	2.0	2.3	5.4	7.8	5.91	4.0	5.9

4.4.10 Correlations

TABLE 4.19 Correlation coefficients of various agronomic characters pooled for the twenty cultivars and four seasons

	Green pod yield ha^{-1}	Green bean yield ha^{-1}	Plant population ha^{-1}	Plant height (cm)	Bottom pod height (cm)	Export marketable pods (%)	Number of pods $plant^{-1}$	100-seed mass (g)	Crude protein (%)
Green bean yield ha^{-1}	0.913 **	-	-	-	-	-	-	-	-
Plant population ha^{-1}	0.319 **	0.203 **	-	-	-	-	-	-	-
Plant height (cm)	0.346 **	0.499 **	0.150 *	-	-	-	-	-	-
Bottom pod height (cm)	0.235 **	0.265 **	0.442 **	0.713 **	-	-	-	-	-
% Export marketable pods	0.123 NS	0.188 *	-0.237 **	-0.090 NS	-0.213 **	-	-	-	-
Number of pods $plant^{-1}$	0.300 **	0.359 **	-0.560 **	0.255 **	-0.073 NS	0.264 **	-	-	-
100-seed mass (g)	-0.265 **	-0.278 **	-0.173 *	-0.142 NS	-0.109 NS	-0.406 **	-0.385 **	-	-
Crude protein (%)	-0.109 NS	-0.090 NS	-0.085 NS	0.316 **	0.225 **	-0.357 **	0.015 NS	0.200 **	-
Fat (%)	0.293 **	0.368 **	0.065 NS	0.521 **	0.232 **	-0.065 NS	0.278 **	-0.087 NS	0.230 **

Figures highlighted in green and red are significantly positive and negative, respectively.

NS = Not significant

4.5 DISCUSSION

Significant interactions were measured between the cultivars and seasons for all the agronomic characteristics studied, as a result of the seasonal variations in the climatic conditions and the plant populations. High temperatures and water stress during the reproductive stages negatively affect flowering and fertilization, increase flower abscission and the numbers of undeveloped pods, pods plant^{-1} and seeds pod^{-1}, and yield (Comlekcioglu and Simsek, 2009; Demirtaş *et al*., 2010; Puteh *et al*., 2013). Vegetable soybean cultivars are more sensitive to high temperatures than grain soybean cultivars (Puteh *et al*., 2013).

Despite the drier conditions in the 2011/12 season, which resulted in a significantly low mean 100-seed mass (Table 4.13.2), the mean green pod, green bean and seed yields (Tables 4.14.2, 4.15.2 and Appendix 5) were significantly higher than in the 2010/11 season. The long dry and hot spells that occurred during flowering and early pod development of the cultivars in the 2010/11 season resulted in a significantly lower number of pods plant^{-1} (Table 4.12.2) and percentage export marketable pods (Table 4.11.2), plus a significantly higher percentage of seedless pods (Appendix 2) than in the 2011/12 season. However, the dry conditions in March 2012 affected the yields of the long-season cultivars more than the short-season cultivars in the 2011/12 season, and consequently no significant differences in green pod yield were measured between the cultivars.

The rainfall received in the 2012/13 season was more similar in quantity and distribution to the long-term mean than in the other two seasons. However, the hailstorm on 31/12/2012 negatively affected the growth and performance of all cultivars in both plantings. Consequently, the mean green pod yields of both 2012/13 plantings were not significantly different to the mean green pod yield obtained in the 2011/12 season. The plant population of the 2012/13 (2nd) season was reduced by the hailstorm and as a result, was significantly lower than the plant population of the 2012/13 (1st) season, but not of the 2010/11 and 2011/12 seasons. Despite this and the later planting date of the 2012/13 (2nd) season, the mean green pod and seed yields were not significantly different to those in the 2012/13 (1st) season. However, the green bean yield was significantly lower due to a significantly higher number of seedless pods (Appendix 2), a significantly lower percentage of export marketable pods (Table 4.14.2) and a significantly lower shelling percentage (Appendix 4). The short-season cultivars had less time to recover from the hailstorm than the long-season cultivars and consequently produced significantly lower green pod, green bean and seed yields (Tables 4.14.2, 4.15.2 and Appendix 5).

The DAP to the various growth stages varied among the seasons due to planting time and temperature (Tables 4.4 – 4.7). The earlier the planting, the longer the cultivars took to reach the various growth stages. Zhang and Kyei-Bohen (2007), Zhang *et al.* (2010) and Liebenberg (2012) reported similar trends. Soybeans are short-day plants and are therefore photoperiod sensitive. They make the transition from the vegetative phase to the flowering phase in direct response to the length of darkness in each 24 hour period, i.e., when the day length is shorter than the critical photoperiod. However, this response is modified by temperature. Each cultivar has a genetically determined response to day-length and temperature (Zhang and Kyei-Bohen, 2007 and James, 2007).

The range in DAP to 50% flowering among the various cultivars was therefore influenced by the above factors and narrowed as their planting date was delayed. The variation in DAP to 50% flowering among the seasons was greater for the longer-season cultivars than the shorter-season cultivars. AGS 437 was the earliest to flower, a mean of 45 DAP, whilst AGS 352, Lightning and the black seeded cultivars, Tanba and Tanbaguro, took the longest to flower, a mean of 75 DAP. James (2007) reported that Tanbaguro was moderately day-length sensitive and therefore, at early planting dates in temperate environments, it was expected to flower very late and to produce excessive vegetative growth and low pod yields. It was therefore potentially better adapted to late spring and summer planting in subtropical environments.

Although AGS 437 was the earliest to flower, AGS 292 and AGS 329 were the earliest to reach green pod harvest, physiological maturity and harvest maturity in all four seasons. Lightning and AGS 352 took the longest DAP to reach green pod harvest, 44 days after AGS 329. AGS 352 took the longest DAP to reach physiological maturity and harvest maturity. Swathi (2009) measured a significant positive correlation between the number of days to 50% flowering and the number of days to maturity.

Zhang *et al.* (2010), Liebenberg (2012) and Sadeghi and Niyaki (2013) reported that sowing date had a significant impact on soybean yield and that the magnitude of the response varied between the cultivars. November is generally the optimum time to plant soybean in South Africa. Due to warmer growing conditions when planting later, the number of days until flowering is reduced and thus the growing season is shortened, which consequently tends to result in fewer pods plant^{-1}, lower seed mass and reduced yields (Sadeghi and Niyaki, 2013).

The green pod harvest window is narrow (Duppong and Hatterman-Valenti, 2005), but may vary depending on the cultivar and environmental conditions at the time of harvest (Zhang and Kyei-Boahen, 2007; Herman, 2010 and Carson *et al.,* 2011). The harvest window did not exceed five days. Harvesting at the correct time (R6) is critical for optimum texture and flavour of edamame. Harvesting too soon results in lower yields, whilst harvesting when the pods have started to yellow will result in a loss of sweetness and digestibility, and the crop will be downgraded or rejected due to its appearance (Herman, 2010).

Early pod shattering, even when the plants still had green stems and some green leaves, was observed in all four seasons with all the cultivars. Seed losses will occur if seed producers do not harvest before pod shattering occurs (Duppong and Hatterman-Valenti, 2005). Uneven ripeness of the pods on the plants was also observed. There is a clear need for breeders to develop non-shattering varieties.

To extend the harvest period, Carson *et al.* (2011) suggested that a range of cultivars with various growing-season lengths could be planted simultaneously, whilst James (2007) suggested multiple sequential planting dates.

A significant interaction was measured among the seasons and cultivars for plant population (Table 4.8.1). Significant positive and negative correlations were measured between plant population and all the agronomic characteristics studied, except crude protein and fat content (Table 4.19). Therefore, inconsistent plant stands affected the results.

Significantly low plant populations were measured for some cultivars in certain seasons. Duppong and Hatterman-Valenti (2005), Sanchez *et al.* (2005) and Hamilton (2007) reported similar observations. Reasons for poor germination and low plant stand were due to poor seed quality resulting from in-field pod fungal diseases and poor post-harvest storage, but may also have been due to some soilborne fungi and bacteria attacking the seeds (Gleekia-Kerkula, 2012; Liebenberg, 2012). The application of a fungicide, thiram, as a seed coating at planting in the 2012/13 season improved mean plant stand significantly above the 2010/11 and 2011/12 seasons. However, the hailstorm on 31/12/2012 significantly reduced the plant population in the 2012/13 (2^{nd}) season.

Despite the thiram application, AGS 440 had consistently low plant populations. This may be a heritable trait and/or it may be related to its large seed size (Table 4.13.2), because a significant negative correlation between 100-seed mass and plant population was measured. To improve seed quality and germination, Khalil *et al.* (2001) recommended late-season plantings for soybean seed production, because smaller seeds with higher germination rates were produced. The brown seeded cultivars, AGS 457 and AGS 458, recorded the highest mean plant population indicating good seed vigor, and possibly, better resistance to fungal pod and seed diseases.

Soybean plants have the ability to adjust their growth habits to account for various spatial distributions and therefore these plant characteristics will respond to different plant populations in order to contribute to maximum yield (Suhre, 2012). The number of branches plant^{-1}, pods plant^{-1}, percentage export marketable pods and 100-seed mass increased significantly as plant population decreased. Soybean plants compensate for low plant populations by producing more branches (Herman, 2010; Christmas, 2008) and pods plant^{-1} (Sharma and Kshattry, 2013; Duppong and Hatterman-Valenti, 2005). Swathi (2009) recorded a significant positive correlation between the number of branches plant^{-1} and pods plant^{-1}. Bekele and Alemahu (2011) reported that soybean seed yield was strongly correlated to the number of pods plant^{-1}, seeds pod^{-1} and seeds plant^{-1}. James (2007) reported that seed mass decreased linearly as plant population increased from 50 000 to 400 000 plants ha^{-1}.

Seed size is genetically controlled, but seed size is modified by environmental factors (Duppong and Hatterman-Valenti, 2005), hence the seasonal variations within the individual cultivars. Mean 100-seed mass was significantly higher in the 2010/2011 season than in the other seasons due to the high rainfall received during pod-fill and the low plant population. Mean 100-seed mass was significantly lower in the 2011/2012 season, due to the low rainfall received between flowering and maturity. Mean 100-seed mass was similar for the two plantings in the 2012/13 season. Significant negative correlations were measured between 100-seed mass and green pod yields, green bean yields and seed yields, indicating that 100-seed mass is not an important contributor to yield.

AGS 440 and the black-seeded cultivars, Tanba and Tanbaguro, produced the highest mean 100-seed masses (> 45 g), whilst Lightning and AGS 352 recorded the lowest mean 100-seed mass (26 g), indicating that the export market requirements of ≥ 30 g 100^{-1} seeds were not met.

Rao *et al*. (2002) reported that seed size was positively correlated to cultivar growing-season length, whilst Sharma and Kshattry (2013) measured a significant negative correlation between the number of days to flowering and 100-seed mass. However, this was not observed in the trial, as Tanba, Tanbaguro, Lightning and AGS 352 had long growing-seasons.

According to Lee *et al*. (2008), soybean yield is relatively insensitive to plant population with a wide range of seeding rates producing the same yield. However, green pod yield, green bean yield and seed yield were significantly positively correlated to plant population. Plant population, in turn, was significantly positively correlated to plant height, which in turn was significantly positively correlated to the number of branches plant^{-1} and pods plant^{-1}. The longer-season cultivars had taller plants with more branches and pods than the shorter-season cultivars and consequently produced significantly higher yields. Hamilton (2007), Zhang and Kyei-Boahen (2007) and Swathi (2009) reported that plant height increased as plant population and cultivar growing-season increased, but Swathi (2009) also measured a significant negative correlation between the number of days to maturity and the number of branches plant^{-1}. Bekele and Alemahu (2011) reported that soybean seed yield was strongly correlated to the number of days to maturity. Sarutayophat (2012) reported significant positive correlations between plant height and the number of marketable pods plant^{-1} and the marketable pod yield.

A significant positive correlation between the number of pods plant^{-1} and percentage export marketable pods was measured. To meet the requirements of the export market and economic success, pods must contain ≥ 2 beans pod^{-1} and therefore the environmental conditions must be suitable for this to occur. Due to the climatic conditions, a mean of 68.7% of the pods contained ≥ 2 beans. The short-season cultivars, AGS 437, AGS 329 and AGS 292, together with the black-seeded cultivars, Tanba and Tanbaguro, produced the lowest percentage export marketable pods. AGS 429 and AGS 425 produced ≥ 76% export marketable pods. Sharma and Kshattry (2013) reported a mean of 86.4% pods with two or more beans for seven cultivars evaluated under irrigation.

The yields of the short-season cultivars, AGS 292 and AGS 329, were disadvantaged by poor seed quality in the 2010/11 season and by hail damage in the 2012/13 season. However, the yields obtained in the 2011/12 season gave an indication of the potential of the short-season cultivars. To produce similar yields to the longer-season cultivars, Edwards *et al*. (2005) and Christmas (2008) recommended higher seeding rates and narrower inter-rows for short-season cultivars. Due to warmer conditions when planting later in the season the plants mature quicker and may produce lower yields per plant. Lee *et al.* (2008) and Zhang *et al*. (2010) therefore recommended higher seeding rates for late planting dates for all cultivars. However, Christmas (2008) and Zhang *et al*. (2010) reported that the yield from short-season soybean cultivars was more stable at late planting dates and therefore seeding rates did not need to be increased.

An advantage of planting higher seeding rates with shorter-season cultivars is an increase in bottom pod height (Table 4.10.2). If mechanical harvesting of the plants is conducted, then low bottom pod heights may result in pod and seed losses. Planting with narrower inter-rows than in this set of experiments (0.75 m) should raise the bottom pod height and improve harvest efficiency (Carson *et al.,* 2011).

The mean green pod yield produced by the various cultivars ranged from 7.36 t ha^{-1} (AGS 440) to 12.07 t ha^{-1} (Lightning) with an overall mean of 9.72 t ha^{-1} (Table 4.14.2). These yields were higher than those obtained by Carson *et al.* (2011), which ranged from 5.61 t ha^{-1} to 8.43 t ha^{-1}, with a mean of 7.32 t ha^{-1}. Sharma and Kshattry (2013) recorded a mean green pod yield of 13 t ha^{-1} with a range from 11.58 t ha^{-1} to 14.46 t ha^{-1}. Mentreddy *et al.* (2002) and Comlekciouglu and Simsek (2011) reported green pod yields up to 22 t ha^{-1} and 34 t ha^{-1}, respectively.

The mean green bean yields for the various cultivars ranged from 3.62 t ha^{-1} (AGS 292) to 4.66 t ha^{-1} (Lightning), with an overall mean of 4.95 t ha^{-1} (Table 4.15.2). Mean shelling percentage was 50.8% (Appendix 4), whilst seed yield was 46.5% of green bean yield.

Sharma and Kshattry (2013) recorded a mean seed yield of 2.6 t ha^{-1}. The mean seed yields obtained in the three seasons were 1.78, 2.32 and 2.55 t ha^{-1} for the 201011, 2011/12 and 2012/13 seasons, respectively (Appendix 5). In comparison, the mean seed yields obtained in the National Grain Soybean Cultivar Evaluation trial conducted at Cedara in the 2010/11, 2011/12 and 2012/13 seasons were 2.39, 3.18 and 3.68 t ha^{-1}, respectively (Erasmus, 2011; de Beer, 2012; de Beer, 2013). This indicates that grain soybean cultivars commercially available in South Africa yield better than the vegetable soybean cultivars evaluated in this experiment. Zhang *et al.* (2009) reported that vegetable soybean produced significantly lower yields of dry seed than grain soybean.

Zhang *et al* (2009) reported that vegetable soybean seed had higher crude protein contents than grain soybean. Mean crude protein ranged from 41.1% (AGS 418) to 44.5% (AGS 335) with an overall mean of 42.6%, which was higher than the mean crude protein (39.6%) of grain soybean cultivars evaluated at Cedara from 2010/11 to 2012/13 (Erasmus, 2011; de Beer; 2012, de Beer, 2013).

The highest mean percentage fat was measured in the 2012/13 (2^{nd}) season and the lowest in the 2010/11 season. Mean percentage fat ranged from 15.4% (AGS 437) to 19.2% (AGS 352) with an overall mean of 17.0%, which was lower than the fat percentage (18.9%) measured for the grain soybean cultivars evaluated at Cedara during the 2010/11 to 2012/13 seasons (Erasmus, 2011; de Beer, 2012; de Beer 2013). Lightning produced high levels of crude protein (43.7%) and fat (18.8%).

Crude protein was negatively but non-significantly correlated to yield. However, crude protein and fat, and fat and yield, were significantly, positively correlated. Crude protein is usually negatively correlated to fat and often to yield, whilst yield and fat content are usually positively correlated (Rao *et al.*, 2002; Bekele and Alemahu, 2011; Popovic *et al.*, 2012). The longer-season cultivars, which produced higher yields, also produced higher percentages of fat.

Research work conducted on the Cedara Research Station with various seeding rates indicated that cultivars optimize production at different seeding rates depending on their growing-season length. Therefore, for cultivars to express their agronomic characteristics optimally in cultivar evaluation trials, different seeding rates should possibly be applied depending on each cultivar"s growing-season length. Higher seeding rates will then be required for short-season cultivars than for long-season cultivars.

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FIGURE 4.1 Mature seeds of four edamame cultivars. When picked at the R6 growth stage, the beans of all the cultivars are bright green.

CHAPTER 5

INFLUENCE OF PHOSPHORUS AND POTASSIUM APPLICATIONS ON THE PRODUCTION OF TWO VEGETABLE SOYBEAN CULTIVARS

5.1 ABSTRACT

Two vegetable soybean (*Glycine max* (L.) Merrill) cultivars, AGS 353 and Lightning, were hand-planted on 22/11/2012 and 21/11/2013 on the Cedara Research Station, KwaZulu-Natal, South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), at 266 667 seeds ha^{-1}. The Hutton soil had means of 44.5% clay, 57.9 mg L^{-1} K and 8.2 mg L^{-1} P before five potassium (K) rates of 0, 40, 80, 120 and 160 kg ha^{-1} and three phosphorus (P) rates of 0, 30 and 60 kg ha^{-1} were applied as potassium chloride (50% K) and single superphosphate (10.5% P), respectively. The fertilizers were hand-broadcast and incorporated with a tractor-drawn offset-disc harrow and konskilde. The trial had a randomized complete block design with three replicates. The plots were split for cultivar. The split-plots consisted of four rows of 5 m length, with an inter-row spacing of 0.75 m. Plant population was significantly higher in the 2012/13 season for both cultivars, but had no significant effect on mean pod and bean dry matter (DM) yields. Lightning produced significantly taller plants, more pods $plant^{-1}$, a higher percentage of export marketable pods and total plant, pod and bean DM yields than AGS 353. P application rate had no significant effect on plant and bottom pod height. Plant height increased significantly as a result of 0 to 120 kg K ha^{-1}, whilst bottom pod height decreased significantly, due to significantly higher percentages of seedless pods as K application rate decreased. The number of pods $plant^{-1}$ was significantly higher at 60 kg P ha^{-1}, but K application rate had no significant effect on the number of pods $plant^{-1}$. Pod and bean DM yields increased significantly from 0 to 60 kg P ha^{-1}. Plant, pod and bean DM yields increased significantly from 0 to 40 kg K ha^{-1}. Significant interactions were measured for pod and bean DM yields between the seasons, cultivars and K applications. In the 2012/13 season Lightning produced significantly lower pod and bean DM yields at 0 kg K ha^{-1}, but no significant differences were measured in the 2013/14 season. In the 2013/14 season, AGS 353 produced a significantly lower pod DM yield at 0 kg K ha^{-1} than at 40 and 120 kg K ha^{-1}, whilst a significantly lower bean DM yield was produced at 0 kg K ha^{-1} than from 40 to 120 kg K ha^{-1}. In the 2012/13 season no significant differences in pod DM yield were measured for AGS 353 among the K application rates. However, at 0 kg K ha^{-1}, bean DM yield was significantly lower than at 120 kg K ha^{-1}.

Key words: Vegetable soybean, phosphorus, potassium, yield

5. 2 INTRODUCTION

Soybean tolerates a wide range of soil conditions, but yields best on well-drained, fertile lands (Birch *et al.*, 1990). They have a considerable macronutrient requirement, which varies according to soil and climatic conditions, cultivar, yield level, cropping system and management practices. With vegetable soybean, yield, flavour and quality are influenced by cultivar selection and soil fertility (Konovsky *et al.*, 1994).

Research conducted in KwaZulu-Natal in the mid-1980s indicated that grain soybean responds strongly to direct fertilization, especially where the soil levels of phosphorus (P) and potassium (K) were medium to low (Birch *et al*. 1990). Imas *et al.* (2007) found that a 3 t ha^{-1} soybean crop is able to extract 240 kg of nitrogen (N), 45 kg of P and 100 kg of K. The withdrawal of nutrients per ton of soybean seed was approximately 60 kg of N, 5 - 6 kg of P and 18 - 19 kg of K. Approximately 70% of the N and P, and 55% of the K taken up by the plant is removed from the land in the seed (Birch *et al.*, 1990). Soybean can produce optimally at lower soil potassium levels than maize, but will remove five times the amount of potassium per ton of seed than maize. Therefore, soil potassium levels need to be monitored closely when maize is grown after soybean to prevent a yield reduction (Liebenberg, 2012).

Soybean, if effectively inoculated with *Rhizobium* bacteria at planting and grown in soils with a satisfactory pH (6.0), can supply its own N requirements. If well nodulated, yields as high as 3 to 4 t ha^{-1} can be produced in South Africa. However, N fixation is inhibited by high levels of mineral N in the soil, by drought stress and by poor soil aeration. K is very important to N fixation, because it stimulates early root growth, thus ensuring early nodulation. In addition, K ensures that the roots have the necessary carbohydrates for optimum nodule functioning. Studies have shown that nodule number and weight, and total N accumulation in the plant increased as the supply of K increased (Imas *et al.*, 2007).

K not only improves yields and water use efficiency, but also benefits various quality aspects. Oil and protein content are improved and larger seeds are produced (Chauhan, 2007), which are essential factors in the production of quality edamame. Drought tolerance and the plants" resistance to pests and diseases are also improved (Imas *et al.*, 2007; Tomar *et al.*, 2007). Isoflavones, which are associated with the prevention and treatment of cancer, diabetes, hypertension and heart disease, have been found to increase with increased levels of K fertilization in soybean (Rajcan *et al.*, 2000; Chauhan, 2007).

The critical level of soil K for soybean has been found to be 80 mg L^{-1} (Birch *et al.*, 1990). However, Rhem *et al*. (2001) recommended that K applications were necessary at soil test levels of below 120 ppm. K is not immobilized in most South African soils and soybean is able to utilize K-reserves well. In KwaZulu-Natal soybean does not react to K fertilizer applications when the soil K-status is above 80 - 90 mg kg^{-1}, but where a K-deficiency occurs, soybeans react well to K-fertilization (Farina, 1992; Liebenberg, 2012). Soils that have been analyzed to show medium to low levels of available K should receive 30 to 60 kg ha^{-1} of K, respectively (Birch *et al*, 1990). However, as soybean is generally used in a rotation with maize and removes fairly large quantities of K, the fertilizer recommendations provided by the Fertilizer Advisory Services (Fertrec) of the KwaZulu-Natal Department of Agriculture and Rural Development are based on a critical soil K level of 100 mg L^{-1} to ensure that the subsequent maize crop receives sufficient K. Farina (1992) reported that maize required a soil test of 110 mg L^{-1} to yield optimally.

K-deficiency symptoms are characterized by yellowing of the leaf margins. These generally appear between late flowering and early pod-fill (Liebenberg, 2012). As with maize, these deficiency symptoms first appear on the lower leaves. With maturity, the deficiency symptoms expand to leaves closer to the top of the canopy.

P is essential for soybean growth, pod development, yield and seed quality and can be absorbed until late in the pod-fill stage (Liebenberg, 2012). A lack of this element may prevent other nutrients from being absorbed by the plants (Sharma *et al.*, 2011). In KwaZulu-Natal soybean is widely grown in soils where P is strongly adsorbed by the soil, making it unavailable to the crop (Birch *et al.,* 1990 and Liebenberg, 2012). At soil P test levels below 10 ppm (Bray 1), P applications would be required to achieve the expected soybean yield (Rhem *et al*., 2001). Barbagelata *et al*. (2002) reported significant responses in yield to P application when the soil P levels were below 9.5 ppm.

Waluyo *et al.* (2004) reported that P increased the number of soybean nodule primordia and therefore had an important role in the initiation of nodule formation. Kumaga *et al.* (2004) and Bekere and Hailemariam (2012) reported that the number of nodules per plant increased with the application of P. Zarrin *et al*. (2007) reported that the combination of *Rhizobia* and P increased nodulation and seed yield. Zheng *et al.* (2010) found that soybean yields improved with P application under drought stress conditions. Shahid *et al.* (2009) and Sharma *et al.* (2011) reported that plant height, the number of branches $plant^{-1}$ and pods $plant^{-1}$, and yield increased as P applications increased. Birch *et al.* (1990), Mahamood *et al.* (2009) and Sharma *et al.* (2011) reported that grain soybean cultivars responded differently to inadequate soil P levels.

P deficiency is characterized by paler and smaller leaves, shorter plants and premature defoliation of the lower leaves (Liebenberg, 2012). Oil and protein content may also be affected (Yu *et al*, 2008; Win *et al.*, 2010; Liebenberg, 2012), although Nedić (2005) found no effect.

5.3 MATERIALS AND METHODS

The experiment was conducted on the KwaZulu-Natal Department of Agriculture and Rural Development"s (KZN DARD) Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The mean annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2012/13 and 2013/14 seasons were received from the Agricultural Research Council - Institute of Soil, Climate and Water"s (ARC-ISCW) automatic weather station on the Cedara Research Station.

5.3.1 Land preparation

The experimental site, Land C1 Range 3, had a Hutton soil form with an orthic A over a red apedal B and a depth > 1 m. Soil samples taken from each plot in July 2012 revealed that the acid saturation ranged from 1% to 7% and the clay percentage ranged from 43% to 46%. A mean soil-test of 57.9 mg K L^{-1} and of 8.2 mg P L^{-1} was measured before the treatments were imposed. The Soil Analytical Laboratory of the KZN DARD at Cedara recommended a target soil-test of 100 mg K L^{-1} and 12 mg P L^{-1}.

Dry beans had been grown on the land in the 2011/12 season. The land was tilled with a tractor-drawn offset mouldboard disc and a konskilde prior to planting in November.

5.3.2 Fertilization and planting

In the 2012/13 and 2013/14 seasons phosphorus was applied as single superphosphate (10.5% P) at three rates, namely 0, 30 and 60 kg P ha^{-1}. Potassium was applied as potassium chloride (50% K) at five rates, namely 0, 40, 80, 120 and 160 kg K ha^{-1}. The identical plots were used for the same treatment in both seasons. Immediately after the fertilizer treatments had been manually broadcast onto each plot, the soil was tilled with a konskilde to incorporate the fertilizers into the soil. The rows were then opened using a hand-held V-shaped hoe and the seed, which had been coated with the fungicide, thiram, at 150 g 100 kg^{-1} seed, was hand-planted at a seeding rate of 266 666 seeds ha^{-1}. The *Bradyrhizobium japonicum* Kirchner inoculant, Soycap (Strain WB 74 containing1 x 10^9 colony-forming units $gram^{-1}$, Soygro[1]) was mixed in water and sprayed over the seed in the row using a knapsack sprayer fitted with a Lurmark DT 30 flat spray nozzle applying 250 L ha^{-1}. Immediately thereafter the seed was covered with about 2 cm of soil using a hand-held rake. The experiments were planted on 22 November 2012 and 21 November 2013. The cultivars used were AGS 353 and Lightning. The crop was grown under dry-land (rain-fed) conditions.

Soil samples were taken from each split-plot after planting and submitted for analysis to the Soil Analytical Laboratory of the KZN DARD at Cedara.

5.3.3 Weed, insect and disease control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[2]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[3]) were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray-nozzle. The post-emergence herbicides bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) and fluazifop-P-butyl (Fusilade Super® EC, 125 g a.i. L^{-1}, Syngenta) were applied five weeks after planting at 1440 and 600 g a.i. ha^{-1}, respectively, with a knap-sack sprayer fitted with a Lurmark DT 30 flat spray nozzle.

The insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[4]), was applied at 400 g a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®, 125/250 g a.i. L^{-1}, Du Pont de Nemours[5]) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle.

[1] Soygro (Pty) Ltd., P.O. Box 5311, Kockspark, Potchefstroom, 2523. Tel.: 018 2921907.
[2] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.
[3] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860. www.basf.co.za.
[4] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.
[5] Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

5.3.4 Data collection

Flowering date (R1) was determined when 50% of the plants in the centre two rows had at least one flower. The green pod harvest (R6) date occurred when the pods were green and the beans occupied 80 – 90% of the pod, with the lower leaves of the plants starting to turn yellow.

All the plants from the centre 3 m of the two middle rows were counted and hand-cut with secateurs at ground level after plant height and bottom pod height had been measured from five randomly selected plants in each of the two rows. The plant mass per split-plot was weighed using an Adam® CFW-60 platform scale (Supplier: Adam Equipment, Johannesburg, South Africa). The number of branches plant^{-1} was determined from ten randomly selected plants. The pods were removed and the number of seedless, 1-, 2- and 3-seeded pods counted. The pods were weighed and a grab-sample of 800 g was shelled to determine bean yield. Ten randomly selected plants without the pods were used to determine the dry matter percentage of the plant residues (stem, branches and leaves). The residues, an 800 g pod sample and the bean sample (approximately 400 g) were weighed and then placed in an oven set at 70°C until dry for approximately 48 hours to determine dry matter content.

After harvesting the 2012/13 crop, all remaining plant residues were manually removed from the experimental site. Soil samples were taken after harvesting in both seasons.

5.3.5 Statistical analysis

A randomized complete block design with three replicates was used. The plots were split for cultivar. Each split-plot consisted of four rows of 5 m length and an inter-row spacing of 0.75 m. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

5.4 RESULTS

5.4.1 Soil P and K levels at planting

As the target soil test of P is 12 mg L^{-1}, the actual P levels were low at 0 and 30 kg P ha^{-1}, particularly in the 2013/14 season (Table 5.1). Soil K levels were considerably lower than the critical K soil target of 80 mg L^{-1} (Table 5.2). The lower levels of soil K in the 2013/14 season were probably due to luxury uptake of K during the 2012/13 season.

TABLE 5.1 Soil P levels for the P application rates at planting in the two seasons

	P application rate (kg ha^{-1})		
	0	30	60
Season		(mg L^{-1})	
2012/13	6.9	10.0	11.9
2013/14	5.9	8.2	10.5

TABLE 5.2 Soil K levels for the K application rates at planting in the two seasons

	K application rate (kg ha^{-1})				
	0	40	80	120	160
Season			(mg L^{-1})		
2012/13	51.9	74.4	96.3	117.7	142.4
2013/14	56.9	65.3	88.3	103.8	103.5

5.4.2 Climatic conditions

The total rainfall received in the 2012/13 season was similar to the long-term mean and was more evenly distributed than in the 2013/14 season (Table 5.3). A large quantity of rainfall was received in March 2014, but a below-average quantity was received in March 2013.

TABLE 5.3 Rainfall (mm) recorded at Cedara during the two growing-seasons

Month	2012/13	2013/14 (mm)	Long-term mean*
November	106	105	112
December	121	138	130
January	123	98	135
February	131	96	121
March	73	240	110
Total	**554**	**677**	**659**

*93 years" data (ARC-ISCW).

The figures highlighted in red and green indicate months with considerably lower and higher rainfall than the long-term mean, respectively.

In both seasons the maximum monthly temperatures from December to April were warmer than the long-term mean (Table 5.4). The minimum monthly temperatures in both seasons were fairly similar to the long-term mean.

TABLE 5.4 Maximum and minimum monthly temperatures recorded at Cedara for the two growing-seasons

Month	Maximum temperature 2012/13	Maximum temperature 2013/14	Maximum temperature Long-term mean*	Minimum temperature 2012/13	Minimum temperature 2013/14	Minimum temperature Long-term mean*
	(°C)					
November	22.7	25.5	23.6	12.3	12.5	12.4
December	26.3	24.0	24.9	14.9	13.6	13.9
January	26.7	27.7	25.4	15.3	15.6	14.9
February	27.2	28.2	25.4	14.8	15.7	14.9
March	25.0	26.3	24.7	14.0	14.0	13.7
Mean	**25.6**	**26.4**	**24.8**	**14.3**	**14.3**	**14.0**

*93 years" data (ARC-ISCW).

The figures highlighted in red indicate months with maximum temperatures considerably higher than the long-term mean.

The cultivar, Lightning, had a longer growing-season than AGS 353 and received more rainfall from 50% flowering to green pod harvest in both seasons (Table 5.5).

TABLE 5.5 Number of days after planting (DAP) to 50% flowering and green pod harvest, rainfall received within twelve days after 50% flowering and from 50% flowering to harvest, and bean dry matter yield for the two cultivars in the 2012/13 and 2013/14 seasons

Season	Cultivar	50% Flowering	Green pod harvest	Rainfall after 50% flowering*	Rainfall from 50% flowering to harvest	Bean DM yield
		(DAP)		(mm)		(kg ha^{-1})
2012/13	AGS 353	56	104	17.3	174.0	1 216 d
	Lightning	74	126	51.6	183.6	2 101 a
2013/14	AGS 353	60	103	46.7	205.7	1 427 c
	Lightning	73	124	35.3	287.0	1 869 b

*Rainfall received within 12 days after 50% flowering

During pod development visual signs of potassium deficiency (yellowing on the edges of the leaves) were evident in the plots where no potassium had been applied (Figure 5.1). This observation was made in both seasons. Only in the 2013/14 season were visual signs of phosphorus deficiency (pale leaves) evident in the plots where no phosphorus had been applied (Figure 5.2).

FIGURE 5.1 Potassium deficiency symptoms in the plants in the row on the right hand side.

FIGURE 5.2 The pale leaves are a sign of phosphorus deficiency. Note the dark colour of the leaves in the left hand row in Fig. 1.

5.4.3 Plant population

Plant population ha^{-1} was recorded at green pod harvest. A significant interaction was measured for plant population between the seasons and cultivars (Table 5.6). A significantly higher plant population ha^{-1} was recorded in the 2012/13 season than the 2013/14 season (Figure 5.3). Lightning had a significantly higher plant population ha^{-1} than AGS 353 in the 2013/14 season, but not in the 2012/13 season.

Plant population was significantly negatively correlated to plant height, bottom pod height, total plant DM yield, residue DM yield and percentage export marketable pods, but significantly positively correlated to percentage seedless pods and shelling percentage (Table 5.18).

TABLE 5.6 ANOVA table of plant population for the two cultivars at the phosphorus and potassium application rates for two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	122.89	**	7545	-
Cultivar	10.99	**	2714	-
Season x cultivar	36.11	**	7370	-
Phosphorus (P) application rate	1.55	NS	4308	-
Potassium (K) application rate	0.83	NS	5562	-
Season x P application rate	0.21	NS	7963	-
Season x K application rate	0.47	NS	9169	-
Cultivar x P application rate	1.43	NS	5387	-
Cultivar x K application rate	0.30	NS	6954	-
P x K application rate	0.58	NS	9633	-
Season x P x K application rate	0.85	NS	14252	-
Season x cultivar x P application rate	0.19	NS	9002	-
Season x cultivar x K application rate	0.49	NS	10817	-
Cultivar x P x K application rates	1.42	NS	12045	-
Season x cultivar x P x K application rates	1.13	NS	17533	3.7

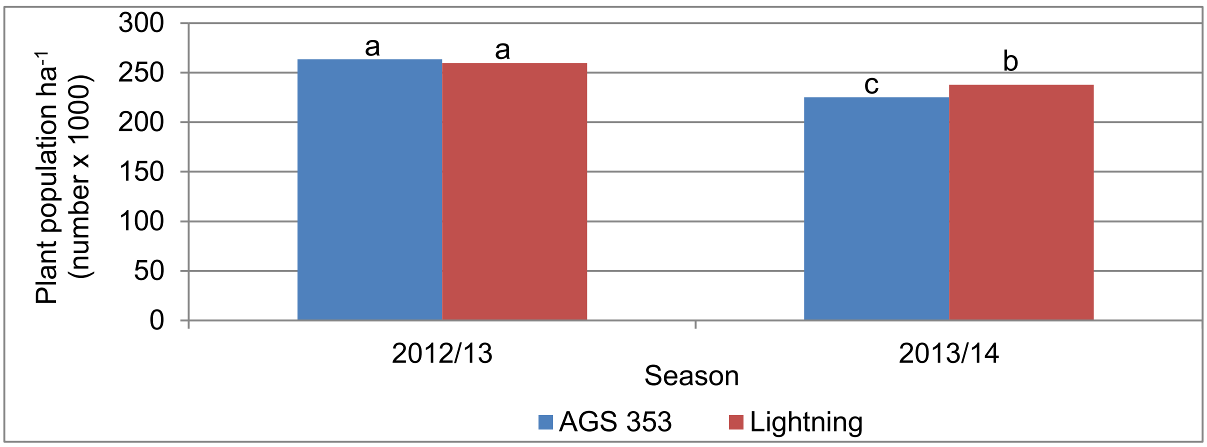

FIGURE 5.3 Plant population ha^{-1} of the two cultivars in the two seasons

5.4.4 Plant height

A significant interaction was measured between the cultivars and seasons for plant height (Table 5.7). Lightning had significantly taller plants than AGS 353 in both seasons (Figure 5.4). The plants of both cultivars were significantly taller in the 2013/14 season than in the 2012/13 season.

A significant interaction was measured for plant height between the two seasons and three P application rates (Figure 5.5). Plant height was significantly taller in the 2013/14 season than in the 2012/13 season at all the P application rates and significantly taller at 60 kg P ha^{-1} than at 0 kg P ha^{-1} in the 2013/14 season. Overall, P had no effect on plant height.

A significant interaction was measured for plant height between the cultivars, three P application rates and five K application rates (Figure 5.6). At all P and K applications, Lightning had significantly taller plants than AGS 353. Mean plant height for the two seasons was significantly shorter at 0 kg K ha^{-1} than at the other K applications, whilst at 40 kg K ha^{-1}, mean plant height was significantly shorter than at 120 kg K ha^{-1}.

Plant height was significantly positively correlated to bottom pod height, residue DM yield, pods plant^{-1}, percentage export marketable pods, pod and bean DM yields and shelling percentage, but significantly negatively correlated to plant population and percentage seedless pods (Table 5.18).

TABLE 5.7 ANOVA table of plant height for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	101.44	**	3.007	-
Cultivar	980.12	**	1.043	-
Season x cultivar	53.51	**	3.708	-
Phosphorus (P) application rate	1.54	NS	1.764	-
Potassium (K) application rate	5.50	**	2.277	-
Season x P application rate	3.77	*	3.199	-
Season x K application rate	1.38	NS	3.708	-
Cultivar x P application rate	2.09	NS	2.157	-
Cultivar x K application rate	2.13	NS	2.784	-
P x K application rates	0.71	NS	3.944	-
Season x P x K application rates	0.50	NS	5.811	-
Season x cultivar x P application rate	0.65	NS	3.584	-
Season x cultivar x K application rate	0.41	NS	4.314	-
Cultivar x P x K application rates	2.55	*	4.822	-
Season x cultivar x P x K application rates	0.92	NS	7.009	4.6

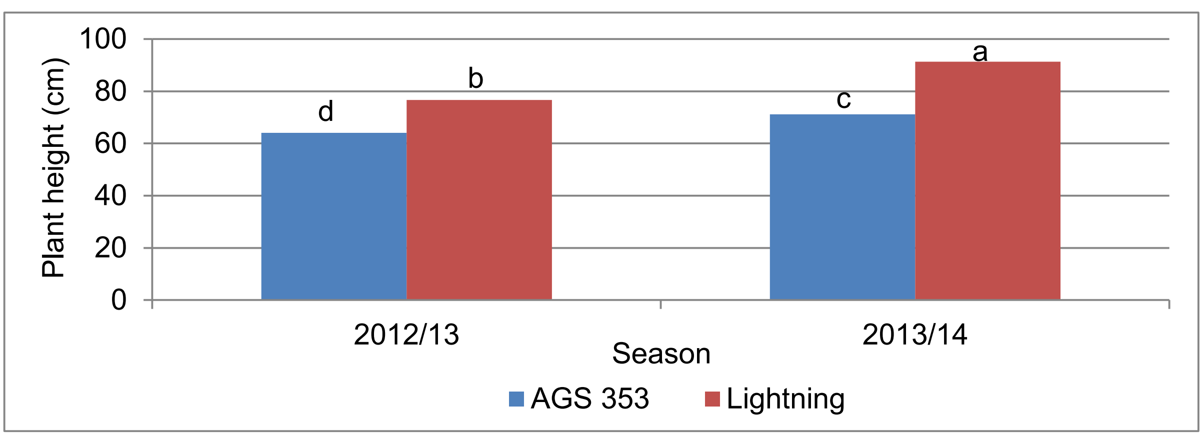

FIGURE 5.4 Plant height of the two cultivars in the two seasons

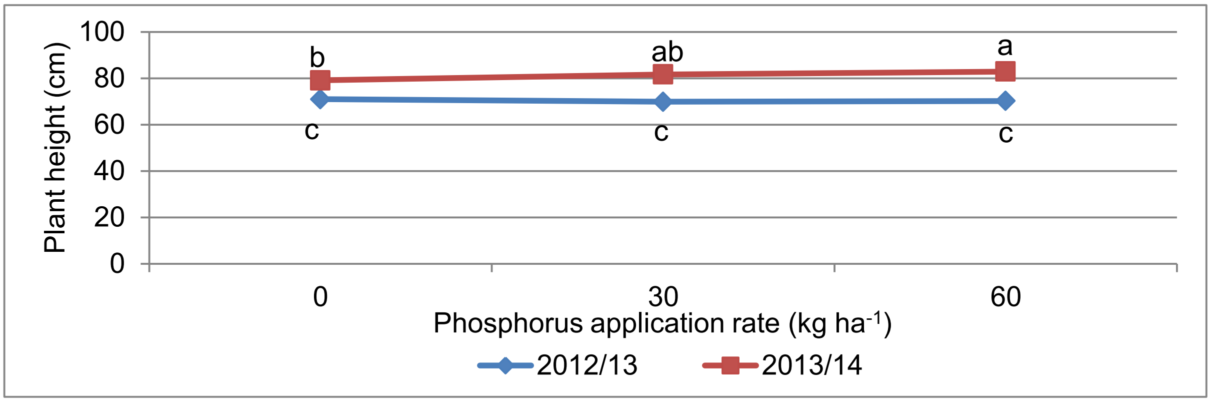

FIGURE 5.5 Mean plant height at the three P application rates in the two seasons

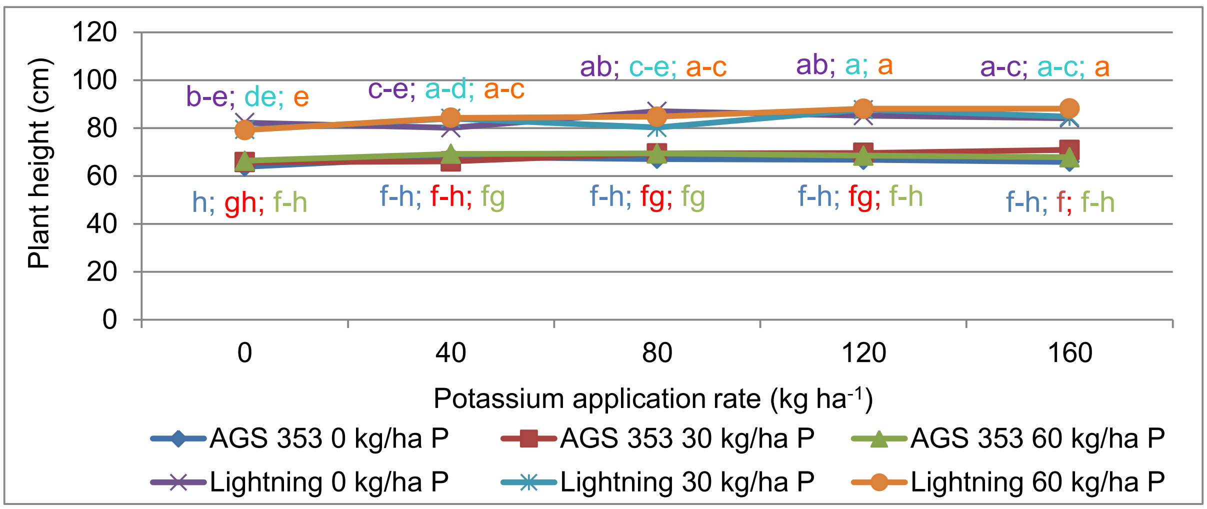

FIGURE 5.6 Plant height of the two cultivars at the three P and five K application rates

5.4.5 Bottom pod height

Bottom pod height was significantly higher in the 2013/14 season than in the 2012/13 season (Figure 5.7).

A significant interaction was measured between the cultivars and K application rates for mean bottom pod height for the two seasons (Table 5.8). At 80 kg K ha^{-1} Lightning had a significantly lower bottom pod height than AGS 353, whilst at the other K application rates no significant differences were measured among the cultivars (Figure 5.8). Mean bottom pod height for the two cultivars decreased significantly with increasing K application rate.

Bottom pod height was significantly positively correlated to plant height, residue DM yield and percentage export marketable pods, but significantly negatively correlated to plant population, percentage seedless pods and shelling percentage (Table 5.18).

TABLE 5.8 ANOVA table of bottom pod height for the two cultivars at the phosphorus and potassium application rates for two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	94.72	**	1.053	-
Cultivar	0.04	NS	0.536	-
Season x cultivar	2.13	NS	1.053	-
Phosphorus (P) application rate	1.52	NS	0.703	-
Potassium (K) application rate	5.78	**	0.907	-
Season x P application rate	0.86	NS	1.172	-
Season x K application rate	2.07	NS	1.401	-
Cultivar x P application rate	0.73	NS	0.952	-
Cultivar x K application rate	2.58	*	1.229	-
P x K application rates	1.41	NS	1.571	-
Season x P x K application rates	0.55	NS	2.276	-
Season x cultivar x P application rate	2.66	NS	1.460	-
Season x cultivar x K application rate	1.11	NS	1.816	-
Cultivar x P x K application rates	0.77	NS	2.128	-
Season x cultivar x P x K application rates	0.57	NS	3.049	9.1

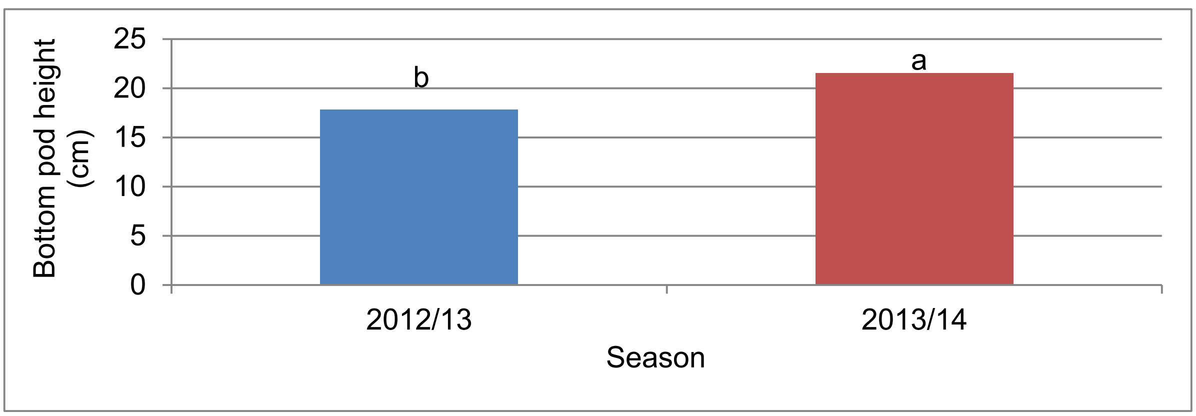

FIGURE 5.7 Mean bottom pod height in the two seasons

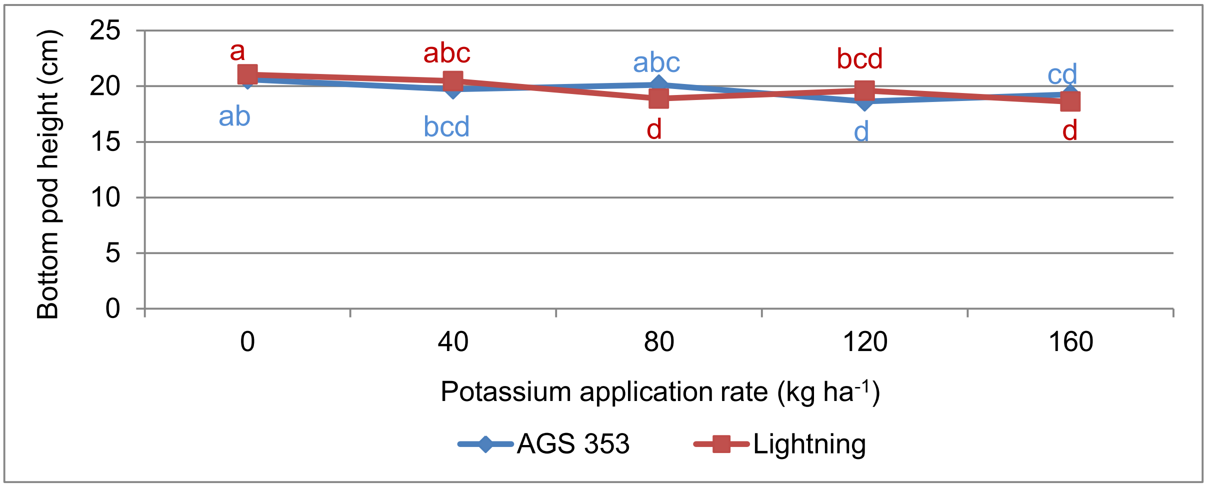

FIGURE 5.8 Bottom pod height for the two cultivars at the five K application rates

5.4.6 Total plant DM yield at green pod harvest

A significant interaction was measured for mean plant DM yield between the cultivars and seasons (Table 5.9). Plant DM yield was significantly higher in the 2013/14 season than in the 2012/13 season (Figure 5.9). Lightning had significantly more plant growth than AGS 353 in both seasons.

A significant interaction was measured for mean plant DM yield between the P application rates and seasons (Table 5.9). Plant DM yield was significantly higher at 30 and 60 kg P ha^{-1} than at 0 kg P ha^{-1} in the 2013/14 season and significantly higher than all three P application rates in the 2012/13 season (Figure 5.10).

A significant interaction was measured for mean plant DM yield between the cultivars and K application rates (Figure 5.11). Lightning had significantly higher plant DM yields than AGS 353 at all the K application rates. At 0 and 40 kg K ha^{-1}, Lightning had significantly lower plant DM yields than at 80 and 160 kg K ha^{-1}. At 0 kg K ha^{-1}, AGS 353 had a significantly lower plant DM yield than at the other K application rates. Mean plant DM yield for the two cultivars was significantly lower at 0 kg K ha^{-1} than at the other four K application rates.

Total plant DM yield was significantly positively correlated to residue, pod and bean DM yields, plant height, number of pods plant^{-1}, percentage export marketable pods and shelling percentage, whilst significantly negatively correlated to plant population ha^{-1} and percentage seedless pods (Table 5.18).

TABLE 5.9 ANOVA table of plant dry matter (DM) yield ha^{-1} for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	27.68	**	542.9	-
Cultivar	754.98	**	188.3	-
Season x cultivar	6.21	*	530.0	-
Phosphorus (P) application rate	8.39	**	337.9	-
Potassium (K) application rate	5.34	**	436.3	-
Season x P application rate	3.74	*	588.8	-
Season x K application rate	0.70	NS	692.2	-
Cultivar x P application rate	1.00	NS	405.3	-
Cultivar x K application rate	3.29	*	523.3	-
P x K application rates	0.82	NS	755.6	-
Season x P x K application rates	0.26	NS	1103.8	-
Season x cultivar x P application rate	0.12	NS	658.6	-
Season x cultivar x K application rate	1.01	NS	799.4	-
Cultivar x P x K application rates	0.48	NS	906.3	-
Season x cultivar x P x K application rates	1.91	NS	1311.1	6.9

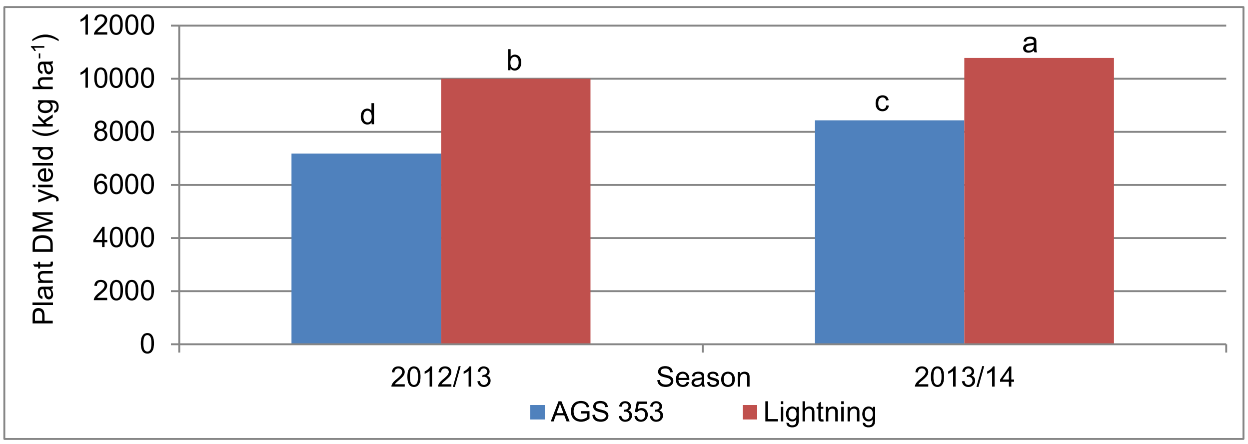

FIGURE 5.9 Plant DM yield ha^{-1} for the two cultivars in the two seasons

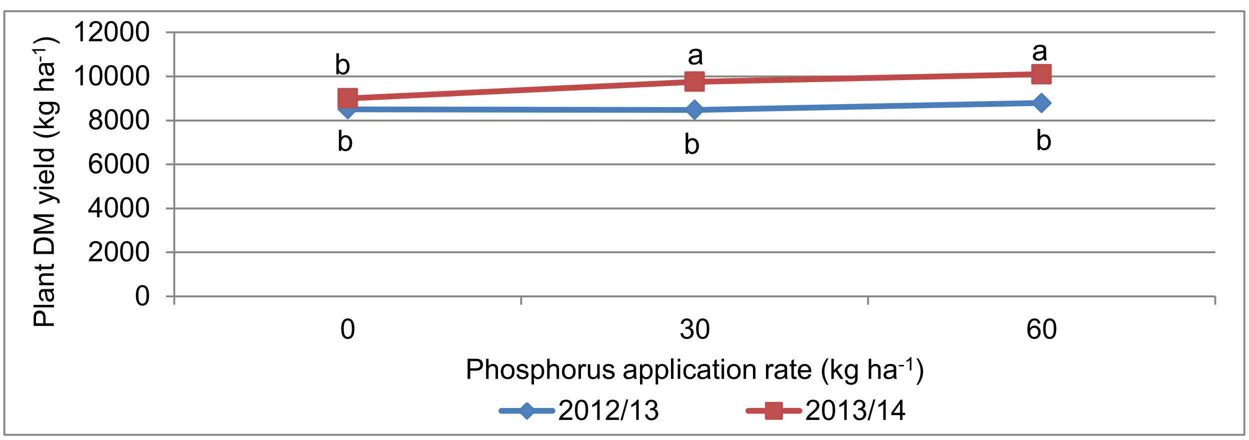

FIGURE 5.10 Plant DM yield ha^{-1} at the three P application rates in the two seasons

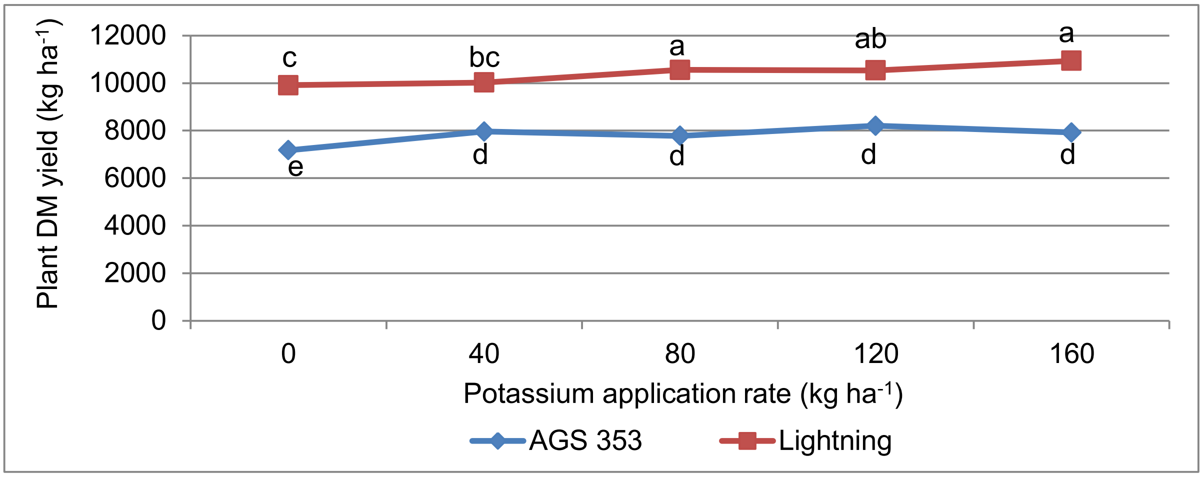

FIGURE 5.11 Plant DM yield ha^{-1} for the two cultivars at the five K application rates

5.4.7 Residue dry matter yield (Leaves, stems and branches)

A significant interaction was measured for residue DM yield ha^{-1} between the seasons and cultivars (Table 5.10). Lightning produced significantly more residue than AGS 353 in both seasons (Figure 5.12). Mean residue DM yield was significantly higher in the 2013/14 season than in the 2012/13 season.

Mean residue DM yield for the two seasons was significantly higher at 30 and 60 kg P ha^{-1} than at 0 kg P ha^{-1} (Figure 5.13).

A significant interaction was measured for residue DM yield between the K application rates and the two seasons (Table 5.10). At 0 kg K ha^{-1} no significant differences in residue DM yield were measured between the seasons (Figure 5.14). From 40 to 160 kg K ha^{-1} significantly higher residue DM yields were measured in the 2013/14 season than in the 2012/13 season, with the residue DM yields being significantly higher from 80 to 160 kg K ha^{-1} than at 0 and 40 kg K ha^{-1}.

Residue DM yield was significantly positively correlated to plant height, bottom pod height, pods plant^{-1}, percentage export marketable pods, pod and bean DM yield and shelling percentage, but significantly negatively correlated to plant population and percentage seedless pods (Table 5.18).

TABLE 5.10 ANOVA table of residue dry matter yield ha^{-1} for the two cultivars at the phosphorus and potassium application rates for two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	186.66	**	187.7	-
Cultivar	277.30	**	139.3	-
Season x cultivar	12.65	**	206.0	-
Phosphorus (P) application rate	7.76	**	241.2	-
Potassium (K) application rate	1.84	NS	311.4	-
Season x P application rate	1.94	NS	310.9	-
Season x K application rate	3.57	*	416.2	-
Cultivar x P application rate	0.65	NS	292.7	-
Cultivar x K application rate	2.01	NS	377.8	-
P x K application rates	0.88	NS	539.4	-
Season x P x K application rates	0.24	NS	748.5	-
Season x cultivar x P application rate	1.21	NS	389.2	-
Season x cultivar x K application rate	0.82	NS	514.8	-
Cultivar x P x K application rates	1.34	NS	654.4	-
Season x cultivar x P x K application rates	1.13	NS	914.1	9.8

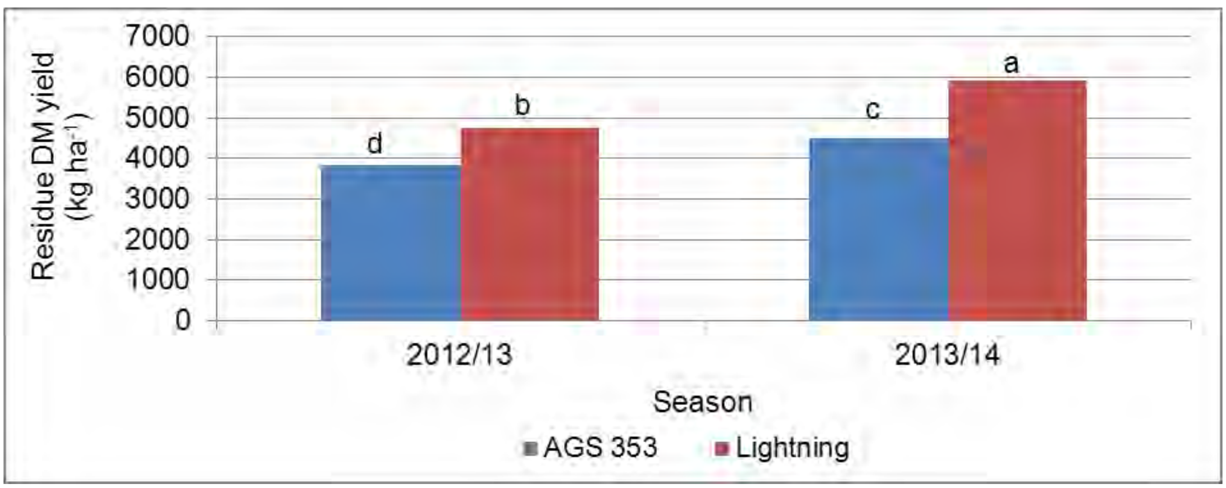

FIGURE 5.12 Residue DM yield ha^{-1} for the two cultivars in the two seasons

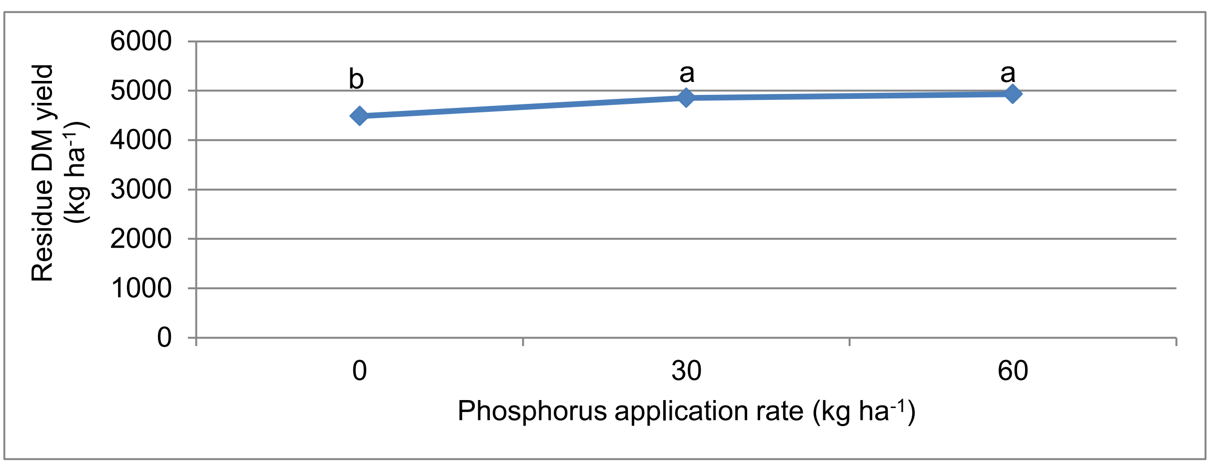

FIGURE 5.13 Residue DM yield at the three P application rates

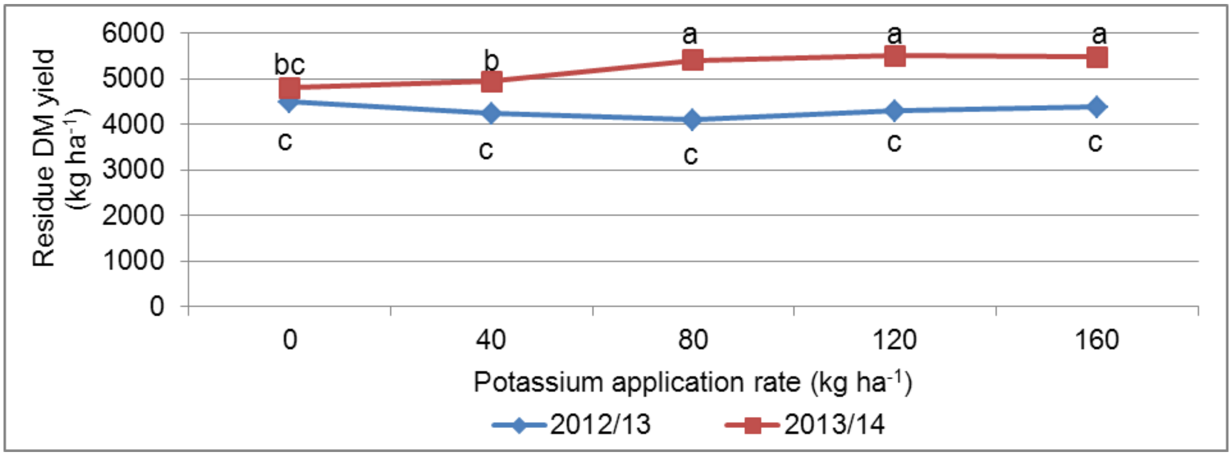

FIGURE 5.14 Residue DM yield ha^{-1} at the five K application rates in the two seasons

5.4.8 Pods

5.4.8.1 Seedless pods

A significant interaction was measured for percentage seedless pods between the cultivars and seasons (Table 5.11). AGS 353 had significantly more seedless pods than Lightning in the 2012/13 season, but not in the 2013/14 season (Figure 5.15). Mean percentage seedless pods was significantly higher in the 2012/13 season.

A significant interaction was measured for mean percentage seedless pods among the cultivars and P and K application rates (Table 5.11). Mean percentage seedless pods was significantly lower at 0 kg P ha^{-1} than at the two higher P application rates and decreased significantly with increasing K application rate (Figure 5.16).

Percentage seedless pods was significantly positively correlated to plant population, but significantly negatively correlated to plant height, bottom pod height, residue DM yield, pods $plant^{-1}$, percentage export marketable pods, pod and bean DM yield, and shelling percentage (Table 5.18).

TABLE 5.11 ANOVA table of percentage seedless pods for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	88.84	**	2.637	-
Cultivar	204.76	**	0.851	-
Season x cultivar	106.23	**	2.574	-
Phosphorus (P) application rate	11.62	**	1.432	-
Potassium (K) application rate	12.12	**	1.849	-
Season x P application rate	0.71	NS	2.746	-
Season x K application rate	1.42	NS	3.124	-
Cultivar x P application rate	0.68	NS	1.754	-
Cultivar x K application rate	0.78	NS	2.265	-
P x K application rates	0.96	NS	3.203	-
Season x P x K application rates	0.57	NS	4.778	-
Season x cultivar x P application rate	0.05	NS	3.034	-
Season x cultivar x K application rate	0.62	NS	3.598	-
Cultivar x P x K application rates	2.18	*	3.923	-
Season x cultivar x P x K application rates	0.82	NS	5.748	21.4

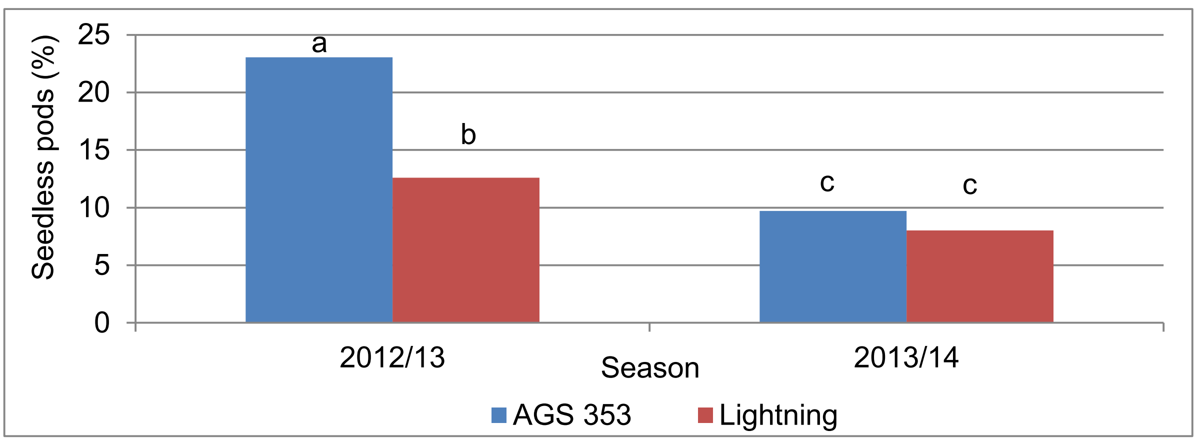

FIGURE 5.15 Percentage seedless pods for the two cultivars in the two seasons

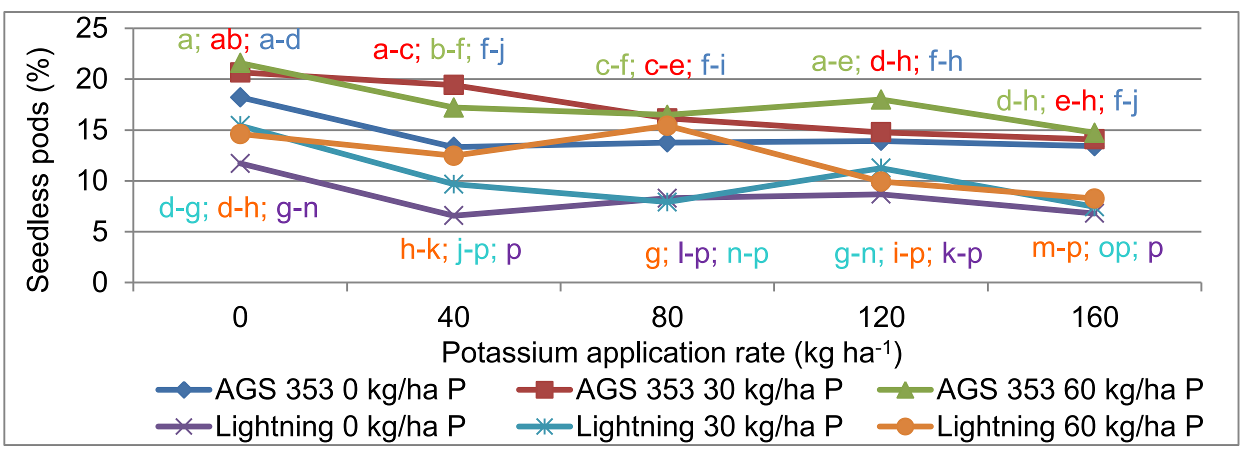

FIGURE 5.16 Percentage seedless pods for the two cultivars at the three P application rates and five K application rates

5.4.8.2 Export marketable pods*

A significant interaction was measured for percentage export marketable pod between the cultivars and seasons (Figure 5.17). Lightning had significantly higher percentages of export marketable pods in both seasons than AGS 353. A significantly higher mean percentage export marketable pods was measured in the 2013/14 season than in the 2012/13 season. Percentage export marketable pods was significantly lower at 0 kg K ha^{-1} than at the other K application rates, among which no significant differences were measured (Figure 5.18).

Percentage export marketable pods was significantly positively correlated to plant height, bottom pod height, residue DM yield, pods $plant^{-1}$, pod and bean DM yield and shelling percentage, but significantly negatively correlated to plant population and percentage seedless pods (Table 5.18).

TABLE 5.12 ANOVA table of percentage export marketable pods for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	75.34	**	1.858	-
Cultivar	271.83	**	0.946	-
Season x cultivar	25.34	**	1.858	-
Phosphorus (P) application rate	1.84	NS	1.228	-
Potassium (K) application rate	9.07	**	1.585	-
Season x P application rate	1.77	NS	2.060	-
Season x K application rate	1.84	NS	2.456	-
Cultivar x P application rate	0.93	NS	1.670	-
Cultivar x K application rate	1.21	NS	2.156	-
P x K application rates	1.92	NS	2.745	-
Season x P x K application rates	1.16	NS	3.980	-
Season x cultivar x P application rate	1.00	NS	2.567	-
Season x cultivar x K application rate	1.56	NS	3.192	-
Cultivar x P x K application rates	1.40	NS	3.734	-
Season x cultivar x P x K application rates	1.29	NS	5.352	4.7

*Export marketable pods are pods containing two or more beans. The length and width of the pods have not been considered, although they are important charcteristics to meet the requirements of the export market.

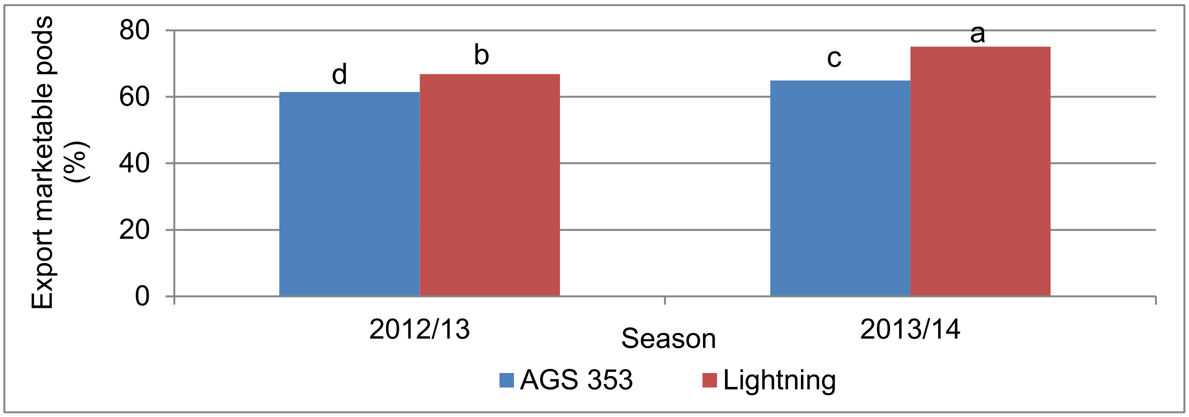

FIGURE 5.17 Percentage export marketable pods of the two cultivars in the two seasons

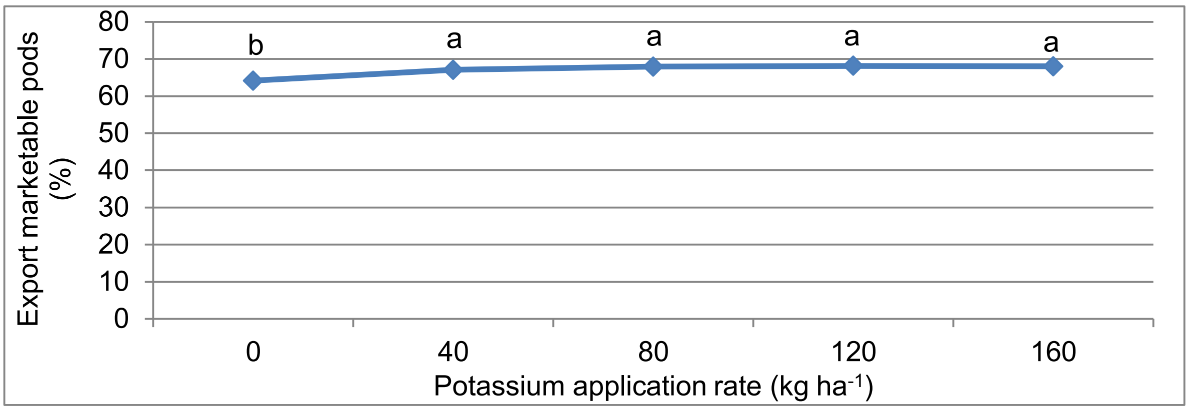

FIGURE 5.18 Percentage export marketable pods at the five K application rates

5.4.8.3 Number of pods plant^{-1}

A significant interaction was measured for number of pods plant^{-1} between the cultivars and seasons (Table 5.13). Lightning produced significantly more pods plant^{-1} than AGS 353 in both seasons, but had a significantly higher number of pods plant^{-1} in the 2012/13 season, whilst AGS 353 had a significantly higher number of pods plant^{-1} in the 2013/14 season (Figure 5.19).

At 60 kg P ha^{-1}, the mean number of pods plant^{-1} was significantly higher than at 0 and 30 kg P ha^{-1} (Figure 5.20).

A significant interaction was measured for mean number of pods plant^{-1} between the cultivars and K application rates (Table 5.13). At 0 kg K ha^{-1}, AGS 353 had a significantly lower number of pods plant^{-1} than at 120 kg K ha^{-1}, whilst at 40 kg K ha^{-1}, Lightning had significantly fewer pods plant^{-1} than at 160 kg K ha^{-1} (Figure 5.21).

The number of pods plant^{-1} was significantly positively correlated to plant height, residue DM yield, percentage export marketable pods, pod and bean DM yield, and shelling percentage, but significantly negatively correlated to percentage seedless pods (Table 5.18).

TABLE 5.13 ANOVA table of number of pods with beans plant^{-1} for the two cultivars at the phosphorus and potassium application rates for two seasons

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	0.93	NS	1.709	-
Cultivar	995.51	**	0.524	-
Season x cultivar	139.71	**	1.669	-
Phosphorus (P) application rate	3.85	*	0.940	-
Potassium (K) application rate	0.84	NS	1.213	-
Season x P application rate	0.36	NS	1.786	-
Season x K application rate	0.97	NS	2.037	-
Cultivar x P application rate	1.22	NS	1.128	-
Cultivar x K application rate	2.96	*	1.456	-
P x K application rates	0.61	NS	2.102	-
Season x P x K application rates	0.44	NS	3.129	-
Season x cultivar x P application rate	1.41	NS	1.954	-
Season x cultivar x K application rate	2.30	NS	2.315	-
Cultivar x P x K application rates	1.69	NS	2.522	-
Season x cultivar x P x K application rates	0.92	NS	3.696	8.7

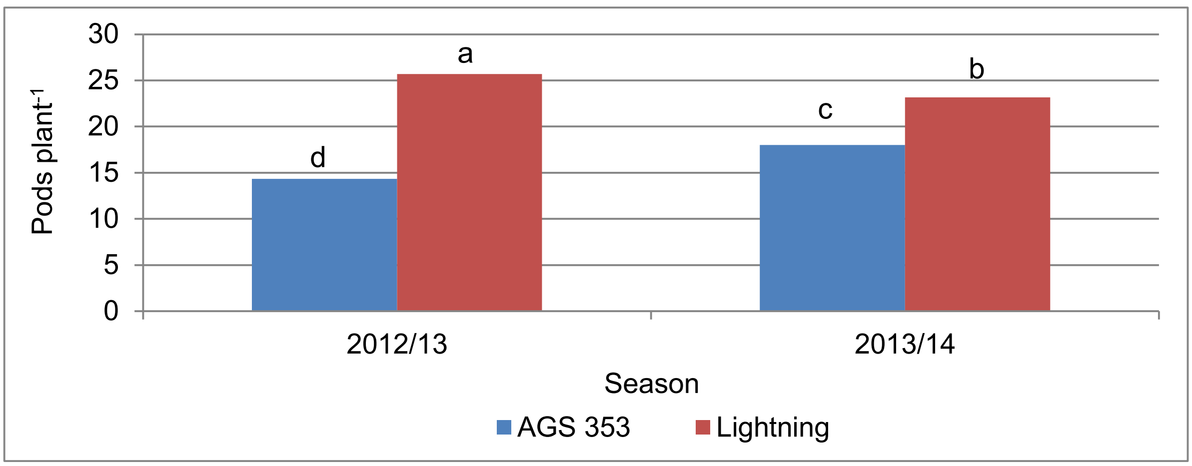

FIGURE 5.19 Number of pods plant^{-1} for the two cultivars in the two seasons

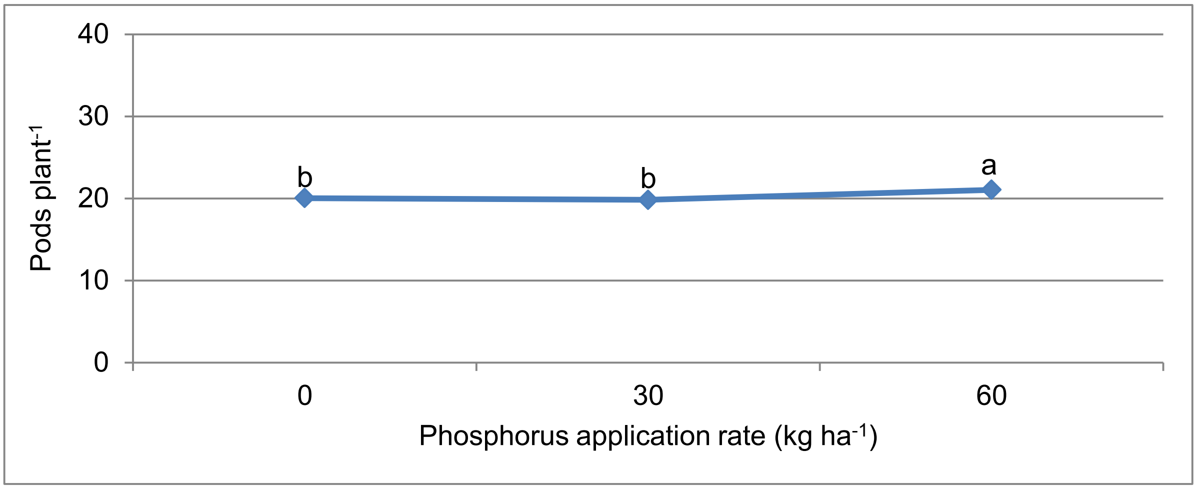

FIGURE 5.20 Number of pods plant^{-1} at the three P application rates

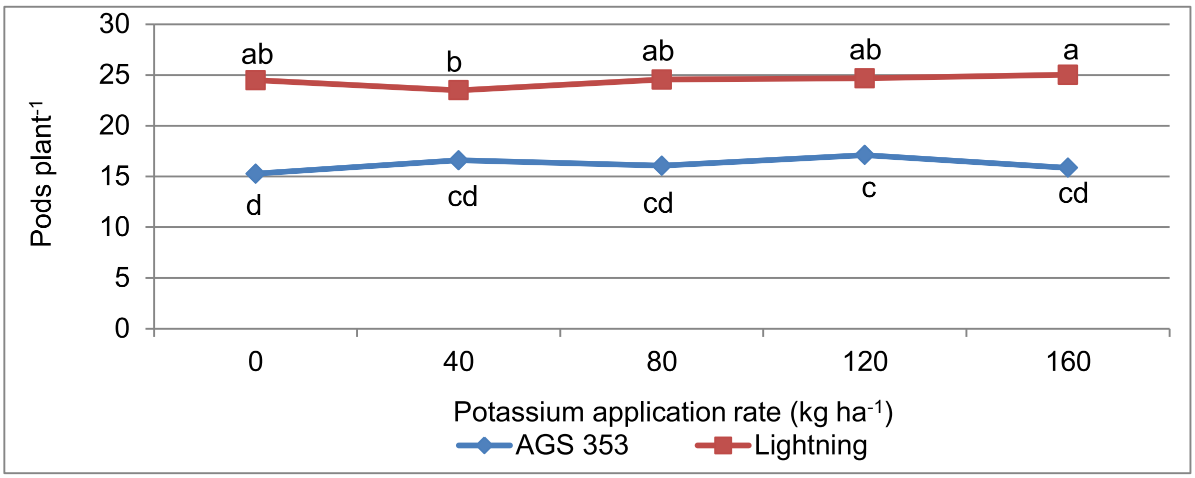

FIGURE 5.21 Number of pods plant^{-1} for the two cultivars at the five K application rates

5.4.9 Pod dry matter yield

Mean pod DM yield for the two seasons was significantly higher at 60 kg P ha^{-1} than at 0 and 30 kg P ha^{-1} (Figure 5.22).

A significant interaction was measured for pod DM yield between the seasons, cultivars and K application rates (Table 5.14). In both seasons Lightning had significantly higher mean pod DM yields than AGS 353 at all K application rates (Figure 5.23). At 0 kg K ha^{-1} Lightning produced a significantly lower pod DM yield than at the other K application rates in the 2012/13 season and at all the K application rates in the 2013/14 season, among which there were no significant differences. AGS 353 produced significantly higher pod DM yields at all K application rates in the

2013/14 season than in the 2012/13 season. At 0 kg K ha^{-1}, the pod DM yield of AGS 353 was significantly lower than at 40 kg K ha^{-1} in the 2012/13 season and at 40 and 120 kg K ha^{-1} in the 2013/14 season. Overall, mean pod DM yield was significantly lower at 0 kg K ha^{-1} than at the other K application rates, among which no significant differences were measured.

Pod DM yield was significantly positively correlated to plant height, residue DM yield, pods plant^{-1}, percentage export marketable, bean DM yield and shelling percentage, but significantly negatively correlated to percentage seedless pods (Table 5.18).

TABLE 5.14 ANOVA table of pod DM yield ha^{-1} for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	1.57	NS	256.1	-
Cultivar	543.82	**	65.4	-
Season x cultivar	63.71	**	250.6	-
Phosphorus (P) application rate	5.52	**	110.5	-
Potassium (K) application rate	7.18	**	142.6	-
Season x P application rate	2.73	NS	255.4	-
Season x K application rate	2.02	NS	275.9	-
Cultivar x P application rate	2.27	NS	135.2	-
Cultivar x K application rate	3.89	**	174.5	-
P x K application rates	1.01	NS	247.0	-
Season x P x K application rates	0.61	NS	387.7	-
Season x cultivar x P application rate	0.93	NS	270.5	-
Season x cultivar x K application rate	4.25	**	305.6	-
Cultivar x P x K application rates	1.79	NS	302.2	-
Season x cultivar x P x K application rates	2.01	NS	458.2	8.2

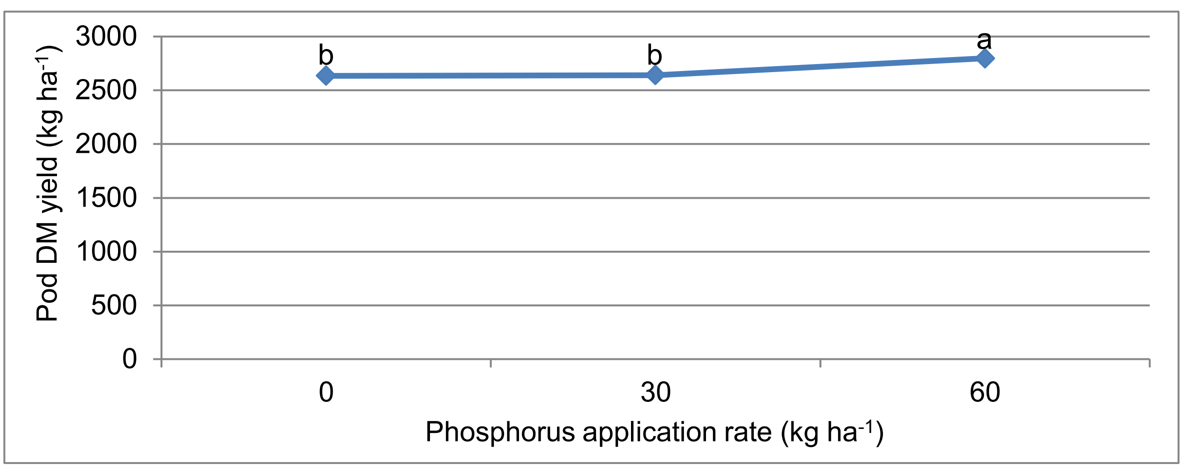

FIGURE 5.22 Pod DM yield at the three P application rates

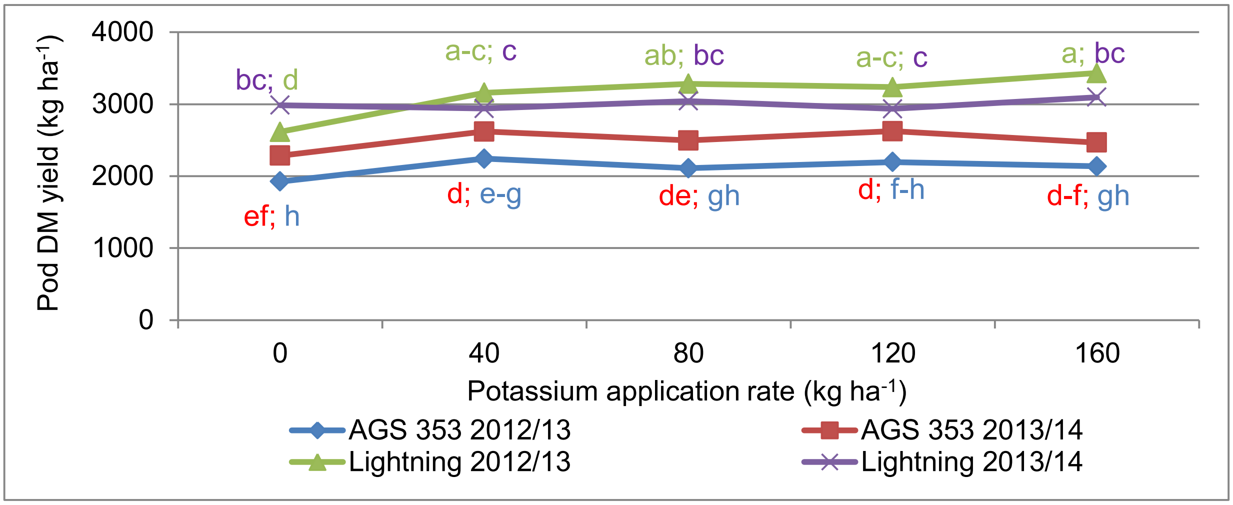

FIGURE 5.23 Pod DM yield for the two cultivars in the two seasons at the five K application rates

5.4.10 Bean dry matter yield

Bean DM yield increased significantly in the 2013/14 season as P application rate increased (Table 5.16).

A significant interaction was measured for bean DM yield among the seasons, cultivars and K application rates (Table 5.15). In both seasons Lightning had significantly higher mean bean DM yields than AGS 353 at all K application rates (Figure 5.24). At 0 kg K ha^{-1} Lightning produced a significantly lower bean DM yield than at the other K application rates in the 2012/13 season, but the yield was not significantly different to the yields in the 2013/14 season from 0 to 120 kg K ha^{-1}. No significant differences in bean DM yield of Lightning were measured at all the K application rates in the 2013/14 season. Lightning had significantly lower mean bean DM yields at 0 and 40 kg K ha^{-1} than at 160 kg K ha^{-1}. AGS 353 produced significantly higher bean DM yields from 40 to 120 kg K ha^{-1} in the 2013/14 season than in the 2012/13 season. AGS 353 had a significantly lower mean bean DM yield at 0 kg K ha^{-1} than at the other K application rates, among which there were no significant differences. Overall, mean bean DM yield was significantly lower at 0 kg K ha^{-1} than at the other K application rates, among which no significant differences were measured.

A significant interaction was measured for bean DM yield with the cultivars and P and K application rates (Table 4.15). For both cultivars, lowest yields occurred where P was applied

(30 or 60 kg ha^{-1}) and 0 kg K ha^{-1} was applied (Figure 5.25). There was little response to K at 0 kg P ha^{-1} and a negative response to P at 0 kg K ha^{-1}. For both cultivars, response to both P and K increased at adequate levels of the other nutrient.

Bean DM yield was significantly positively correlated to plant height, residue DM yield, pods plant^{-1}, percentage export marketable pods, pod DM yield and shelling percentage, but was significantly negatively correlated to percentage seedless pods (Table 5.18).

TABLE 5.15 ANOVA table of bean DM yield ha^{-1}of the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	0.03	NS	175.1	-
Cultivar	804.57	**	46.8	-
Season x cultivar	89.28	**	171.3	-
Phosphorus (P) application rate	3.54	*	78.2	-
Potassium (K) application rate	10.42	**	100.9	-
Season x P application rate	3.71	*	175.5	-
Season x K application rate	1.46	NS	190.9	-
Cultivar x P application rate	2.44	NS	96.0	-
Cultivar x K application rate	3.89	*	123.9	-
P x K application rates	1.86	NS	174.8	-
Season x P x K application rates	0.75	NS	271.9	-
Season x cultivar x P application rate	0.93	NS	187.2	-
Season x cultivar x K application rate	3.46	*	213.2	-
Cultivar x P x K application rates	2.59	*	214.7	-
Season x cultivar x P x K application rates	1.90	NS	323.4	9.5

TABLE 5.16 Bean DM yield at the three P application rates in the two seasons

	Season		
P application rate (kg ha^{-1})	**2012/13**	**2013/14 (kg ha^{-1})**	**Mean**
0	1 694	1 562 b	1 628
30	1 586	1 651ab	1 619
60	1 695	1 730 a	1 713
Mean	**1 658**	**1 648**	**1 653**
F value	2.43	5.00	3.71
P value	NS	*	NS
LSD (P<0.05)	116.9	109.1	175.5
CV%	10.7	8.0	9.5

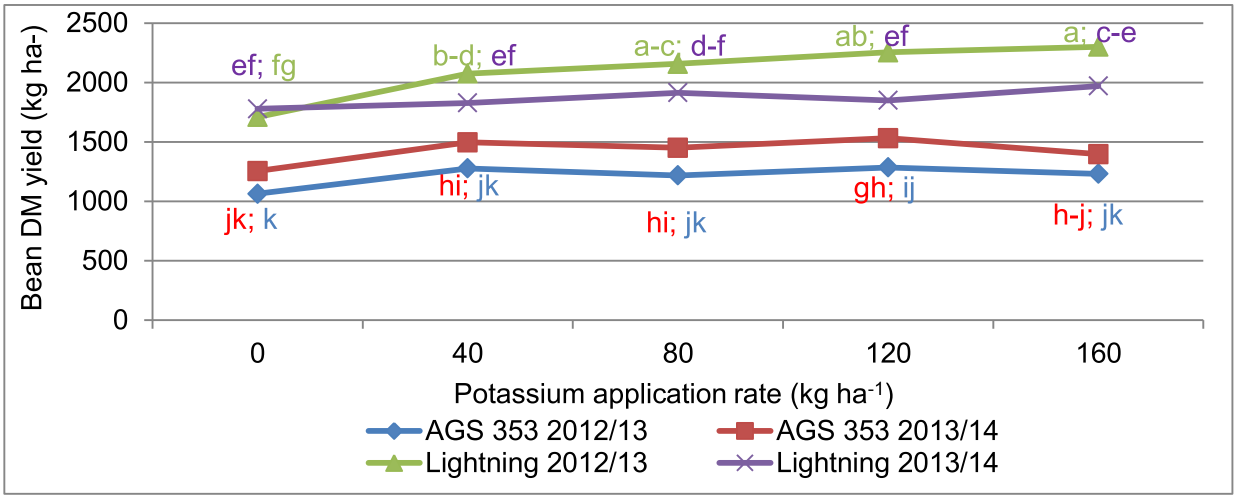

FIGURE 5.24 Bean DM yield ha^{-1} for the cultivars in the two seasons at the five K application rates

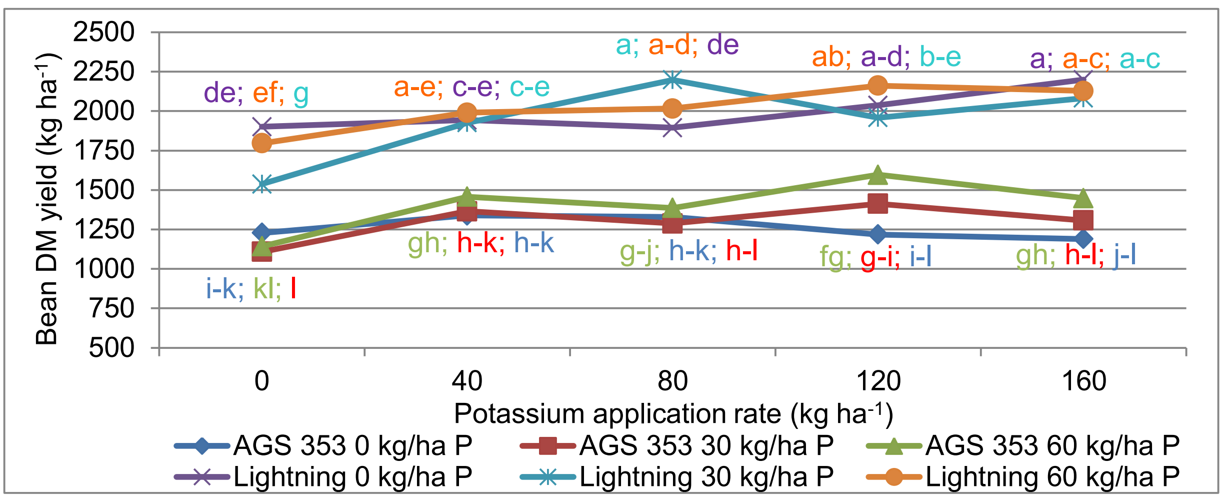

FIGURE 5.25 Bean DM yield ha^{-1} for the two cultivars at the three P and five K application rates

5.4.11 Shelling percentage

A significant interaction was measured for shelling percentage between the seasons and cultivars (Table 5.17). In both seasons Lightning recorded a significantly higher shelling percentage than AGS 353 (Figure 5.26). Lightning recorded a significantly higher shelling percentage in the 2012/13 season than in the 2013/14 season. No significant difference was measured between the two seasons for AGS 353. Overall, shelling percentage increased significantly from 0 to 120 kg K ha^{-1} (Figure 5.27).

A significant interaction was measured for shelling percentage between the P and K application rates (Table 5.17). For 0 kg P ha^{-1}, no significant differences in shelling percentage were measured among the K application rates (Figure 5.28). For 30 kg P ha^{-1}, shelling percentage increased significantly from 0 to 80 kg K ha^{-1}, but thereafter no significant differences were measured. For 60 kg P ha^{-1}, no significant differences in shelling percentage were measured from 0 to 80 kg K ha^{-1}, but the values were significantly lower than at 120 kg K ha^{-1}. Mean shelling percentage was significantly higher over all levels of P at 120 kg K ha^{-1} than at 0 and 40 kg K ha^{-1}.

Shelling percentage was significantly positively correlated to plant population, plant height, residue DM yield, pods plant^{-1}, percentage export marketable pods and pod and bean DM yield, but significantly negatively correlated to percentage seedless pods (Table 5.18).

TABLE 5.17 ANOVA table of shelling percentage for the two cultivars at the phosphorus and potassium application rates in the two seasons

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	24.78	**	1.274	-
Cultivar	270.43	**	0.909	-
Season x cultivar	21.71	**	1.379	-
Phosphorus (P) application rate	0.43	NS	1.037	-
Potassium (K) application rate	9.31	**	1.339	-
Season x P application rate	2.73	NS	1.555	-
Season x K application rate	0.90	NS	1.941	-
Cultivar x P application rate	0.17	NS	1.505	-
Cultivar x K application rate	0.54	NS	1.943	-
P x K application rates	2.31	*	2.319	-
Season x P x K application rates	1.72	NS	3.294	-
Season x cultivar x P application rate	0.61	NS	2.173	-
Season x cultivar x K application rate	0.53	NS	2.775	-
Cultivar x P x K application rates	1.34	NS	3.366	-
Season x cultivar x P x K application rates	0.66	NS	4.772	5.0

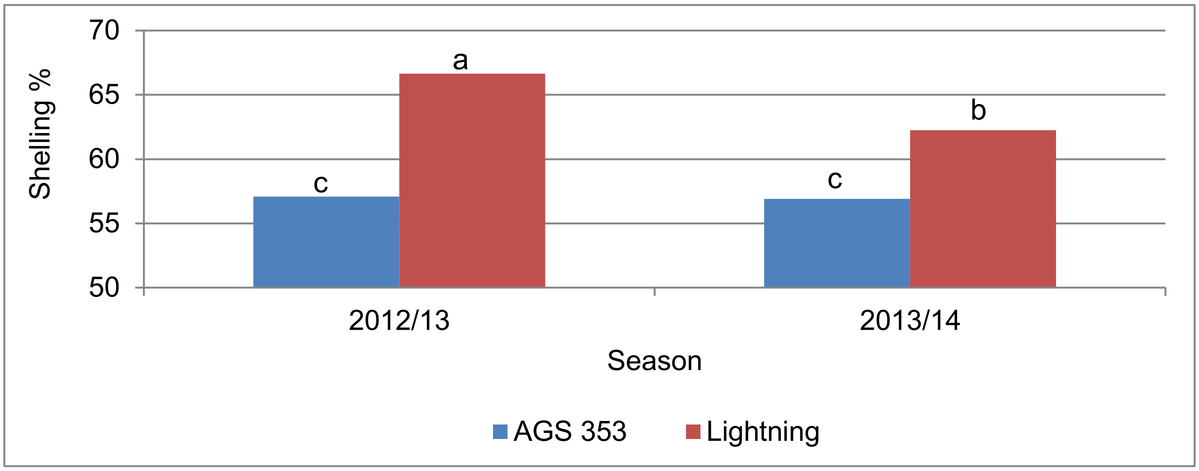

FIGURE 5.26 Shelling percentage of the two cultivars in the two seasons

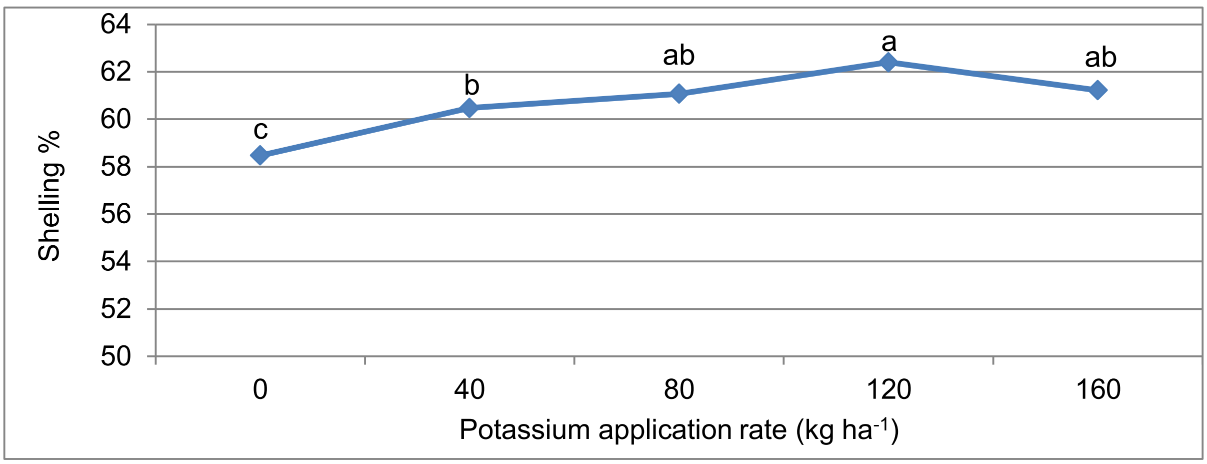

FIGURE 5.27 Shelling percentage at the five K application rates

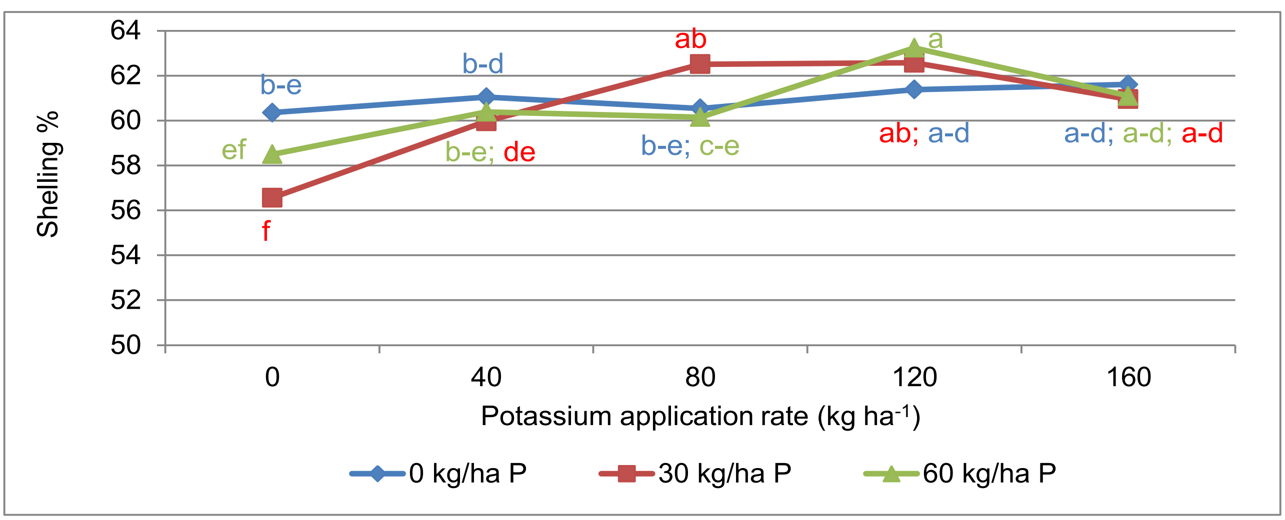

FIGURE 5.28 Shelling percentage for the three P and five K application rates.

5.4.12 Correlations

TABLE 5.18 Correlation coefficients measured for various agronomic characteristics pooled from the two seasons

	Pod DM yield ha^{-1}	Bean DM yield ha^{-1}	Plant population ha^{-1}	Plant height	Bottom pod height	Total plant DM yield ha^{-1}	Residue DM yield ha^{-1}	Pods $plant^{-1}$	% Seedless pods	% Export marketable pods
Bean DM yield ha^{-1}	0.966 **	---	---	---	---	---	---	---	---	---
Plant population ha^{-1}	-0.066 NS	0.036 NS	---	---	---	---	---	---	---	---
Plant height	0.633 **	0.612 **	-0.305 **	---	---	---	---	---	---	---
Bottom pod height	0.016 NS	-0.062 NS	-0.521 **	0.315 **	---	---	---	---	---	---
Total plant DM yield ha^{-1}	0.869 **	0.841 **	-0.184 *	0.840 **	0.146 NS	---	---	---	---	---
Residue DM yield ha^{-1}	0.525 **	0.481 **	-0.294 **	0.827 **	0.268 **	0.874 **	---	---	---	---
Pods $plant^{-1}$	0.844 **	0.847 **	-0.135 NS	0.629 **	0.000 NS	0.810 **	0.560 **	---	---	---
% Seedless pods	-0.590 **	-0.540 **	0.541 **	-0.594 **	-0.370 **	-0.590 **	-0.455 **	-0.532 **	---	---
% Export marketable pods	0.599 **	0.563 **	-0.293 **	0.761 **	0.259 **	0.697 **	0.623 **	0.532 **	-0.642 **	---
Shelling %	0.700 **	0.856 **	0.202 **	0.472 **	-0.170 *	0.625 **	0.317 **	0.673 **	-0.532 **	0.407 **

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant.

5.5 DISCUSSION

The soil tests for P and K of samples taken at planting had lower levels in the 2013/14 season for all the application rates, except at 0 kg K ha^{-1} (Tables 5.1 and 5.2). The plants may have extracted higher levels of P and especially K than required during the 2012/13 season.

Despite receiving almost similar total rainfall from 50% flowering to green pod harvest in the 2012/13 season, the long-season cultivar, Lightning, produced a significantly higher bean DM yield than the medium-season cultivar, AGS 353 (Table 5.3). Lightning benefitted from the high rainfall received in March 2014 and consequently, it produced a significantly higher bean DM yield than AGS 353, which was harvested at the beginning of March. Soybean responds favourably to high soil moisture levels, particularly during pod-fill (James, 2007; Comlekcioglu and Simsek, 2009; Demirtaş *et al*., 2010; Popovic *et al*., 2013). In addition, long-season soybean cultivars usually produce higher yields than shorter-season cultivars, due to having taller plants (Figure 5) bearing more pods (Figure 5.28) (Zhang and Kyei-Boahen, 2007; Swathi, 2009).

Plant height and bottom pod height are usually significantly positively correlated with plant population (Christmas, 2008; Epler and Staggenborg, 2008), but a significant negative correlation was measured, due to the plants having grown taller in the 2013/14 season, despite the lower plant population. The higher rainfall and cooler conditions experienced during December 2013 (Tables 5.3 and 5.4), which coincided with the vegetative growth stages, may have encouraged greater plant growth. The warmer temperatures in January and February 2014 did not adversely affect flowering and pollination, because the number of pods $plant^{-1}$ (Figure 5.17) and percentage export marketable pods (Figure 5.15) were higher in the 2013/14 season. Despite significant variations with the seasons and cultivars (Figure 5.1), plant population ha^{-1} had no significant effect on pod and bean DM yield (Table 5.18). Soybean plants are able to compensate for low plant populations by producing more pods $plant^{-1}$ and seeds pod^{-1} (Kantolic and Slafer, 2007; Epler and Staggenborg, 2008; Bekele and Alemahu, 2011; Suhre, 2012) and therefore the higher number of pods $plant^{-1}$ and percentage export marketable pods were as a result of the lower plant population.

Plant height increased significantly from 0 kg P ha^{-1} to 60 kg P ha^{-1} in the 2013/14 season, but not in the 2012/13 season (Figure 5.3) and when comparing the means of the two seasons. This response may have been due to the wider range in soil P at 0 and 60 kg P ha^{-1} at planting in the

2013/14 season (Table 5.1). Aduloju *et al*. (2009), Mahamood *et al*. (2009); Shahid *et al*. (2009), Sharma *et al*. (2011) and Mokoena (2013) reported that plant height, the numbers of branches plant^{-1}, pods plant^{-1} and seeds pod^{-1}, and yield increased as P application rate increased. The number of pods plant^{-1} and pod DM yield were significantly higher at 60 kg P ha^{-1} than at 0 and 30 kg P ha^{-1} (Figures 5.18 and 5.20). The number of pods plant^{-1} was significantly positively correlated to pod and bean DM yield (Table 5.18). Bishnoi *et al*., (2007), Aduloju *et al*. (2009) and Bekele and Alemahu (2011) reported a similar relationship, with the number of pods plant^{-1} being the most important factor influencing grain yield (Aduloju *et al*., 2009).

Aduloju *et al*. (2009) and Mahamood *et al*. (2009) reported significant variations in P utilization efficiency among soybean genotypes. However, for the two cultivars considered here there were no significant interactions between the cultivars and P application rates for all the agronomic characteristics measured.

An experiment conducted in Madhya Pradesh, Sehore, showed that plant height, the numbers of branches plant^{-1} and pods plant^{-1}, seed weight and pod weight increased with all the K application rates over the control treatment (0 kg K ha^{-1}) (IPI, 2002). Plant height increased significantly as K application increased from 0 to 120 kg K ha^{-1} (Figure 5.4). Mokoena (2013) reported a similar response, whilst Xiang *et al*. (2012) reported that plant height decreased significantly with increasing K application rate.

Bottom pod height decreased significantly with increasing K application rate (Figure 5.6), indicating that the pods positioned lower on the plants tended to be seedless as a result of low soil K. P application rate had no effect on bottom pod height.

K application rate had no significant effect on the number of pods plant^{-1} (Table 5.13), whilst the number of pods plant^{-1} was significantly higher at 60 kg P ha^{-1} than at the lower P application rates (Figure 5.18). However, Xiang *et al*. (2012) reported that the number of pods plant^{-1} increased significantly with increasing K application rates and with P application rates from 0 to 17 kg P ha^{-1}.

AGS 353 produced a significantly higher percentage of seedless pods than Lightning in the 2012/13 season (Figure 5.13). This was probably due to the low rainfall received within 12 days from 50% flowering for AGS 353 (Table 5.5). This resulted in a significantly low number of pods plant^{-1} (Figure 5.17) and low pod and bean DM yields for AGS 353 (Figures 5.21 and 5.22). Shelling percentage was also negatively affected (Figure 5.24). The percentage seedless pods decreased as K application increased, but increased as P application increased (Figure 5.14), indicating that P is required to produce pods, but when the K levels are low, pod abortion occurs or the seeds do not develop in the pod. Xiang *et al*. (2012) reported that the percentage seedless pods increased significantly with decreasing P and K application rates.

The percentage export marketable pods was significantly lower at 0 kg K ha^{-1} than at the other K applications, among which no significant differences were measured (Figure 5.16). P application rate had no effect on the percentage export marketable pods (Table 5.12). However, Xiang *et al*. (2012) reported that the number of seeds pod^{-1} increased significantly from 0 to 22.5 kg P ha^{-1} and from 0 to 75 kg K ha^{-1}.

Plant, pod and bean DM yields of AGS 353 were significantly lower at 0 kg K ha^{-1} than from 40 to 160 kg K ha^{-1}, among which no significant differences were measured. The plant and pod DM yields of Lightning increased significantly with K application from 0 to 80 kg ha^{-1} (Figure 5.9), whilst bean DM yield increased significantly from 0 to 160 kg K ha^{-1}. This result indicated that cultivars may have different K requirements to yield optimally.

Lightning, being a taller growing cultivar than AGS 353, produced a higher total plant DM yield (Figure 5.7). Despite a low plant population, total plant DM yield was significantly higher in the 2013/14 season, possibly due to more favourable growing conditions during the vegetative growing stages. The response of plant DM yield to 30 and 60 kg P ha^{-1} in the 2013/14 season (Figure 5.8) was possibly due to lower soil P values at planting than in the 2012/13 season (Table 1). Mean plant DM yield increased significantly when K was applied at 40 kg ha^{-1}, but no response was obtained at higher K applications (Figure 5.9). However, Lightning displayed a positive response from 0 to 60 kg K ha^{-1}, but not thereafter.

P application rate had no significant effect on shelling percentage, which increased significantly from 0 to 120 kg K ha^{-1} (Figure 5.25). Mean pod DM yield was significantly higher at 60 kg P ha^{-1} than at 0 and 30 kg P ha^{-1} (Figure 5.20). Sharma *et al*. (2011) reported a similar response with grain yield. However, bean DM yield only responded to P application in the 2013/14 season (Table 5.14). No significant interaction was measured between the cultivars and P application rate. However, Birch *et al*. (1990), Mahamood *et al*. (2009) and Sharma *et al*. (2011) reported varying responses to P application among green soybean cultivars. Xiang *et al*. (2012) reported that seed yield increased significantly with increasing K application rate from 0 to 112.5 kg K ha^{-1}, whilst seed yield was significantly higher at 17 kg P ha^{-1} than at 0, 8.5 and 22.5 kg P ha^{-1}.

Birch *et al*. (1990) and Liebenberg (2012) stated that grain soybean grown in KwaZulu-Natal did not have a yield response at soil K levels above 80 - 90 mg L^{-1} at planting. Overall, the vegetable soybean cultivars did not produce significantly higher mean bean DM yields above 74 and 65 mg L^{-1} in the 2012/13 and 2013/14 seasons, respectively, indicating that vegetable soybean K requirements are lower than those of grain soybean. However, Lightning responded better to K application rate than AGS 353 by producing higher bean DM yields at each K application rate, whereas there was no positive response by AGS 353 above 40 kg K ha^{-1}. Lightning therefore required soil K levels above 88 - 96 mg L^{-1} to yield optimally, whilst AGS 353 required soil K levels at 65 – 75 mg L^{-1}.

As bean DM yield was significantly higher at 60 kg P ha^{-1} than at the lower P application rates, soil P levels above 10 mg L^{-1} at planting were required (Rhem *et al*., 2001; Barbagelata *et al*., 2002). However, Liebenberg (2012) proposed that soil P levels of 25 – 30 mg L^{-1} were optimal. Therefore, higher bean DM yields may have been produced by the two vegetable soybean cultivars at higher P applications rates than those evaluated. Although no significant positive interaction was measured between the P and K application rates, there was little response to K at 0 kg P ha^{-1} and a negative response to P at 0 kg K ha^{-1}. For both cultivars, the response to P and K increased at adequate levels of the other nutrient (Figure 5.23), indicating the importance of ensuring that both elements are in sufficient quantity to achieve optimum yields. Overall, the highest bean DM yield was obtained by the combination of 60 kg P ha^{-1} and 120 kg K ha^{-1}.

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CHAPTER 6

THE EFFECT OF FOUR FUNGICIDE SEED TREATMENTS ON THE PRODUCTION OF FOUR VEGETABLE SOYBEAN CULTIVARS

6.1 ABSTRACT

Variable emergence was observed among twenty one cultivars of vegetable soybean (*Glycine max* (L.) Merrill) planted in an evaluation trial at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), KwaZulu-Natal, South Africa. Seed from the same cultivars was then planted on 02/12/2011 in an unreplicated trial at Cedara. Each cultivar was planted in a plot with eight rows of 8 m length and spaced 0.75 m apart. The plots were split for a) the application of the fungicide, thiram, to the seed at planting, and b) no application of thiram. Thiram was applied at a rate of 20 g 16 L^{-1} water with a knapsack sprayer delivering 250 L ha^{-1} to the seed after it had been manually placed in the row at a seeding rate of 266 667 seeds ha^{-1}. Percentage emergence varied significantly between the cultivars and ranged from 2.8% to 98.1%. A significantly higher emergence was obtained when thiram was applied (52.0%) compared to the no thiram application (42.2%). Plant height, bottom pod height and yield were significantly higher when thiram was applied, but 100-seed size was significantly lower.

Two fungicides, thiram, captan and a bio-fungicide, Eco-T®, were applied as seed coatings at planting to four edamame cultivars, AGS 352, AGS 353, AGS 354 and Lightning. The seed was hand-planted at a seeding rate of 266 667 seeds ha^{-1} in trials at the Cedara Research Station in the 2012/13 and 2013/14 seasons. The effect of the fungicides was compared against a Control treatment (no fungicide) on plant population, nodule number $plant^{-1}$, percentage active nodules, plant growth and yield in a randomized complete block design with three replicates. Each plot consisted of 4 rows of 5 m length and spaced 0.75 m apart. The application of thiram and captan resulted in significantly higher plant populations than Eco-T® and the Control treatment. However, no significant differences were measured for nodule number $plant^{-1}$, percentage active nodules, plant height, bottom pod height, 100-seed mass and yield among the four fungicide treatments. The cultivar, Lightning, contained significantly more and larger nodules than the other three cultivars, but a significantly lower percentage of active nodules. AGS 353 and Lightning produced significantly lower mean yields than AGS 352 and AGS 354.

Key words: Vegetable soybean, fungicide, emergence, plant population

6.2 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill), also known as edamame, is a speciality crop produced for human consumption as a green bean. The green pods are harvested at the R6 growth stage when the seeds have filled 80 – 90% of the pods and are almost touching each other (Duppong and Hatterman-Valenti, 2005; Hamilton, 2007). The beans are larger, more tender, have a nuttier flavour and are more digestible than grain soybean (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007).

Researchers have reported the poor emergence of vegetable soybean, that varied considerably from year to year and was not confined to any one cultivar (Duppong and Hatterman-Valenti, 2005; Sanchez *et al*., 2005; Hamilton, 2007). Poor emergence can be attributed to many causes. Seed quality and vigor will decline when high temperatures and/or moisture stress (drought) occur during pod-fill and therefore emergence will be affected (Egli *et al*., 2005; Ren *et al.*, 2009; Khan *et al*., 2011; Liebenberg, 2012). Early- and medium-maturing cultivars may be more susceptible to seed deterioration than later-maturing cultivars when exposed to higher temperatures and more rainfall during pod-fill. These hot and humid conditions may be ideal for an infection of the pod fungal disease caused by *Phomopsis* species*,* which results in seed rot (Li and Chen, 2013). Late planting dates will result in better seed quality because the plants will mature in drier and cooler conditions (Khalil *et al*., 2001). The chance of seed infection by *Phomopsis* species will increase the longer the mature crop is left in the field before harvesting, especially if warm and wet conditions prevail (Gleekia-Kerkula, 2012; Liebenberg, 2012).

Poor post-harvest storage and seed age will affect seed quality and emergence. To ensure good viability and vigor, Mbofung *et al*. (2013) recommended that soybean seed have a moisture content ≤ 10% during storage and that the storage temperature and relative humidity be maintained at 10°C and below 40%, respectively. The authors reported that seed treated with a fungicide before storage had improved viability. According to Shelar *et al*. (2008) and Gleekia-Kerkula (2012) soybean genotypes differed in their ability to maintain seed longevity. The viability of genotypes with high oil contents and low protein contents deteriorated more rapidly. Shelar *et al*. (2008) further observed that smaller soybean seeds had superior storability than larger seed. Edamame cultivars are large seeded, having a 100-seed mass from 25 g to 50 g.

Soil and air temperatures, and soil moisture conditions at planting, soil crusting, and planting depth may also affect germination and emergence (Miles and Sonde, 2002).

Soil- and seed-borne fungi and bacteria, such as *Pythium, Rhizoctonia, Fusarium* and *Phomopsis* species, may also reduce emergence and plant population. These diseases often occur in a complex and are activated under stress conditions such as excessive rain, cold or heat, drought, herbicide damage and poor fertility. An abundance of organic material, such as in no-till fields, may enhance disease levels (Liebenberg, 2012). To market edamame pods early, farmers may be enticed to plant early in the season. The soil may still be cool and wet, which could delay emergence and subject the seed to a greater risk of disease infection (Zhang *et al*., 2010). To ensure good germination, soil temperatures at planting should be >15°C (Liebenberg, 2012). To prevent seed and seedling decay, the application of fungicide seed dressings at planting may therefore be necessary.

It is recommended that good quality certified seed be used for planting. Fungicide seed treatments may be used as a preventative measure against pod- and soil-borne diseases or when unfavourable conditions for germination occur. However, soybean nodulation may be adversely affected by the type of fungicide used and the type of inoculant used (Zilli *et al.*, 2009).

Liebenberg (2012) reported that the fungicide, captan, is detrimental to rhizobial bacteria and nodulation, whilst thiram had little effect, even after long hours of contact. However, Campo *et al*. (2009) reported that the application of both captan and thiram severely reduced the rhizobial population. Andrés *et al*. (1998) found a similar response to thiram. Zilli *et al*. (2009) observed that the combination of carbendazim + thiram reduced nodulation significantly, but concluded that some rhizobial strains may be more affected than others. Despite these reported effects with thiram and captan, the AVRDC – The World Vegetable Center, recommends the use of these two products for the protection of edamame seed against soilborne fungal diseases (Lal *et al*., 2001). Xue *et al*. (2006) reported that the application of thiram was effective in protecting soybean from soil-borne *Rhizoctonia solani* Khun and increased plant emergence and yield.

Isolates of *Trichoderma* species are being used as a bio-fungicide for the suppression of various seed- and soil-borne fungal diseases that cause seed rot and seedling decay in various crops, including soybean. *Trichoderma* also have the ability to improve soybean germination and plant growth (Vinale *et al*., 2008; Tančić *et al*., 2013). Mukhtar *et al*. (2012) reported 96% germination when a strain of T. *harzianum* was applied to soybean seed, which was considerably higher than the control treatment (76%) and strains of other *Trichoderma* species.

T. harzianum is the active ingredient of the product Eco-T®. Studies have shown that Eco-T® increased yields and especially when used as a co-inoculant with *Bradyrhizobia* (Abudulai *et al*., 2014; N‟Cho *et al*., 2013; Du Rand and Laing, 2011).

The objective of the trial was to determine the effect of using thiram, captan and Eco-T® as seed treatments on plant population, nodulation, plant growth and yield of four vegetable soybean cultivars.

6.3 MATERIALS AND METHODS

6.3.1 DEMONSTRATION TRIAL

A vegetable soybean cultivar evaluation trial was conducted in 2011 at the Cedara Research Station of the KwaZulu-Natal Department of Agriculture and Rural Development (KZNDARD), South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). At harvest some *Phomopsis* infected pods were observed. The „dean‟ seed from that trial was planted in November 2011 in a cultivar evaluation trial on the Cedara Research Station. Extremely variable germination was observed among the twenty one cultivars planted. This result led to an evaluation of the effect of applying thiram to seeds of the same twenty one cultivars in a demonstration trial on the Cedara Research Station. The climatic data for 2010 to 2012 was received from the automatic weather station of the Agricultural Research Council – Institute of Soil, Climate and Water (ARC-ISCW) on the Cedara Research Station.

6.3.1.1 Land preparation

The soil was a Hutton form with an orthic A over a red apedal B and had a depth > 1 m. The land had been planted to maize in the preceding season. Soil samples were taken from the land during August of the same planting year and analyzed by the Fertilizer Advisory Services‟ Laboratories of the KZN DARD based on the Cedara Research Station. The lands were cultivated twice with a tractor-drawn offset disc-harrow in spring. Prior to planting, a tractor-drawn konskilde was used.

6.3.1.2 Fertilization and planting

Based on the results of the soil analysis, 20 kg ha^{-1} phosphorus, supplied as single superphosphate (10.5% P), was band-placed in the row and covered with soil. The twenty one cultivars were then hand-planted on 2 December 2011 in an unreplicated demonstration trial. Each plot consisted of eight rows of 8 m length and spaced 0.75 m apart. The seed was planted at a seeding rate of 266 666 seeds ha^{-1}. In four adjacent rows in each split-plot the fungicide, thiram, which had been mixed at a rate of 20 g per 16 litres of water, was applied at a rate of 250 L ha^{-1} onto the seed in the row using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. No fungicide was applied to the other four rows in each plot. Thereafter, the *Bradyrhizobium japonicum* Kirchner inoculant, Soycap (Rate: 250 g / 25 kg seed (2013/14), Strain WB 74, 1 x 10^9 colony forming units/gram; Soygro[1]) was sprayed onto all the rows in the trial using the same knapsack sprayer. The seed was then immediately covered with soil using a garden rake.

6.3.1.3 Weed, insect and disease control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[2]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[3]), were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. The post-emergence herbicide bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) was applied five weeks after planting at 1440 g a.i. ha^{-1} with a knapsack sprayer fitted with a Lurmark DT 30 flat spray nozzle.

An insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[4]), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®; 125/250 g a.i. L^{-1}, Du Pont de Nemours[5]) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle.

[1] Soygro (Pty) Ltd., P.O. Box 5311, Kockspark, Potchefstroom, 2523. Tel.: 018 2921907.

[2] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[3] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

[4] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.

[5] Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

6.3.1.4 Data collection

Five meters of plants in the middle of the two centre rows were evaluated as a net plot for determining plant height, bottom pod height, plant population ha^{-1} and yield ha^{-1}. Plant height was measured from the ground to the top of the highest positioned pod on the plant. Bottom pod height was measured from the ground to the bottom of the lowest positioned pod on the plant. Five randomly selected plants in each of the two middle rows were measured per plot.

All the plants in the net plot were counted at harvest maturity. Percentage emergence was calculated as the number of plants harvested as a percentage of the seeding rate. The plants were hand-harvested using secateurs and the pods were shelled by hand. The seed was weighed and converted to 12.5% moisture content after determining the moisture content using a Sinar GrainPro 6310 Moisture Analyzer (Supplier: Ronin Grain Management Solutions, Modderfontein, South Africa). One hundred randomly selected seeds were counted and weighed to determine 100-seed mass.

6.3.1.5 Statistical analysis

The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

6.3.2 EXPERIMENT

Subsequently, two field trials were conducted over two seasons, from October 2010 to May 2013, at the Cedara Research Station. The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The mean annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2010 to 2013 was received from the ARC-ISCW‟s automatic weather station on the Cedara Research Station. The soil was a Hutton form with an orthic A over a red apedal B and had a depth > 1 m. Soil analyses showed an average of 43.5% clay and 2.9% organic carbon. The average pH (KCl) and acid saturation during the experimental period was 4.49% and 3.5%, respectively (Table 17).

6.3.2.1 Land preparation

Due to the need for crop rotation, different lands were used each season. The lands had been planted to maize in the preceding seasons. Soybean had not been planted on the lands for a minimum of ten years. Soil samples were taken from each land during July or August of the same planting year and analyzed by the Fertilizer Advisory Services‟ Laboratories of the KZN DARD based on the Cedara Research Station. The lands were cultivated twice with a tractor-drawn offset disc-harrow in spring. Prior to planting a tractor–drawn konskilde was used.

6.3.2.2 Fertilization and planting

After tillage the rows were opened using a hand-held V-shaped hoe. Based on the results of the soil analyses (Table 6.11), 20 kg ha^{-1} phosphorus was hand-applied to each row as single superphosphate (10.5% P) and thereafter covered with approximately 1 cm of soil using a garden rake. On 28 November 2012 and 27 November 2013 the seeds of vegetable soybean cultivars AGS 352, AGS 353, AGS 354 and Lightning were moistened with a 5% sugar-water solution and then coated with the following treatments:

1. Thiram WP - Rate: 150 g 100 kg^{-1} of seed (AG -Thiram 800 WP 800 g a.i. kg^{-1})
2. Captan WP - Rate: 115 g 100 kg^{-1} seed (Captab WS 800 a.i. g kg^{-1})
3. Eco-T® - Rate: 1 g kg^{-1} seed (active ingredient (2 x 10^{9} spores g^{-1}) *Trichoderma harzianum* strain kd; fungus; Plant Health Products, P.O. Box 207, Nottingham Road, 3280. Tel.: 033 2666130).
4. Control (no fungicide applied)

6.3.2.3 Pest control

The pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF), were applied at 1189.5 and 50 g a.i. ha^{-1}, respectively, immediately after planting, using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle. The post-emergence herbicide bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) was applied five weeks after planting at 1440 g a.i. ha^{-1} with a knapsack sprayer fitted with a Lurmark DT 30 flat spray nozzle.

The insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®; 125/250 g a.i. L^{-1}, Du Pont de Nemours) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat spray nozzle.

6.3.2.4 Data collection

Six adjacent plants were randomly selected in the first and fourth rows and dug up using a spade. The nodules were counted and dissected to determine whether they were active (pink) or inactive (white, green or brown). In the 2012/13 season only AGS 353 was used to observe nodulation, whilst in the 2013/14 season all four cultivars were used.

At pod maturity, the middle 4 m of the two centre rows were used as a net plot for determining plant height, bottom pod height, plant population ha^{-1} and yield ha^{-1}. Plant height was measured from the ground to the top of the highest positioned pod on the plant. Bottom pod height was measured from the ground to the bottom of the lowest positioned pod on the plant. Both measurements were done using a 1 m steel ruler. Five randomly selected plants in each of the two centre rows were measured per plot. All the plants in the net plot were counted at mature harvest to determine plant population ha^{-1}. The plants were hand-harvested using secateurs and the pods were shelled manually. The seed was weighed and converted to 12.5% moisture content after determining the moisture content using a Sinar GrainPro 6310 Moisture Analyzer. One hundred randomly selected seeds were counted and weighed to determine 100-seed mass.

6.3.2.5 Statistical analysis

A randomized complete block design with three replicates was used. Each plot consisted of four rows, 5 m in length and spaced 0.75 m apart. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

6.4 RESULTS

6.4.1 DEMONSTRATION TRIAL

6.4.1.1 Climatic conditions

The above-average rainfall received in March and April 2011 (Table 6.1) and the warmer temperatures recorded in March 2011 (Table 6.2), which coincided with pod-fill through to harvest maturity, resulted in the development of *Phomopsis* pod infection. The rainfall received in the 2011/12 season was lower than the long-term mean. The drier and warmer conditions, especially from January to April, resulted in low yields being obtained.

TABLE 6.1 Rainfall received during the six month growing period in the two seasons

	Season		
	2010/11	2011/12	Long-term mean*
Month	(mm)		
November	122	123	112
December	130	112	130
January	107	98	135
February	74	45	121
March	114	49	110
April	83	21	51
Total	**630**	**448**	**659**

*93 years" data (ARC-ISCW). The figures highlighted in green and red indicate months with considerably higher or lower rainfall than the long-term mean, respectively.

TABLE 6.2 Maximum and minimum temperatures measured during the six month growing period in the 2010/11 and 2011/12 seasons

	Maximum			Minimum		
	Season		Long-term	Season		Long-term
	2010/11	2011/12	mean*	2010/11	2011/12	mean*
Month	(°C)			(°C)		
November	25.8	23.7	23.6	12.6	11.8	12.4
December	24.2	25.1	24.8	13.7	14.2	12.6
January	25.6	27.1	25.1	15.3	15.7	13.6
February	27.1	27.9	24.9	15.3	16.1	13.5
March	28.8	26.9	23.9	15.2	13.2	11.9
April	22.0	23.3	22.9	10.3	8.6	10.6

*93 years" data (ARC-ISCW). The figures highlighted in red indicate months with considerably warmer maximum and minimum temperatures than the long-term mean.

6.4.1.2 Yield components

Cultivars that matured from 119 to 129 days after planting in the 2010/11 season were more greatly affected by the *Phomopsis* infection than the earlier and later maturing cultivars (Figure 6.1).

A significant negative correlation was measured between 100-seed mass at planting and percentage emergence (Figure 6.2 and Table 6.4). The cultivars that recorded > 90% emergence were the brown-seeded cultivars, AGS 457 and AGS 458.

The application of Thiram resulted in a significant increase in percentage emergence, plant height and yield (Table 6.3), but a significant decrease in 100-seed mass. A significant negative correlation was measured between 100-seed at planting and yield (Table 6.4). The effect was greater when Thiram was not applied (Figure 6.3).

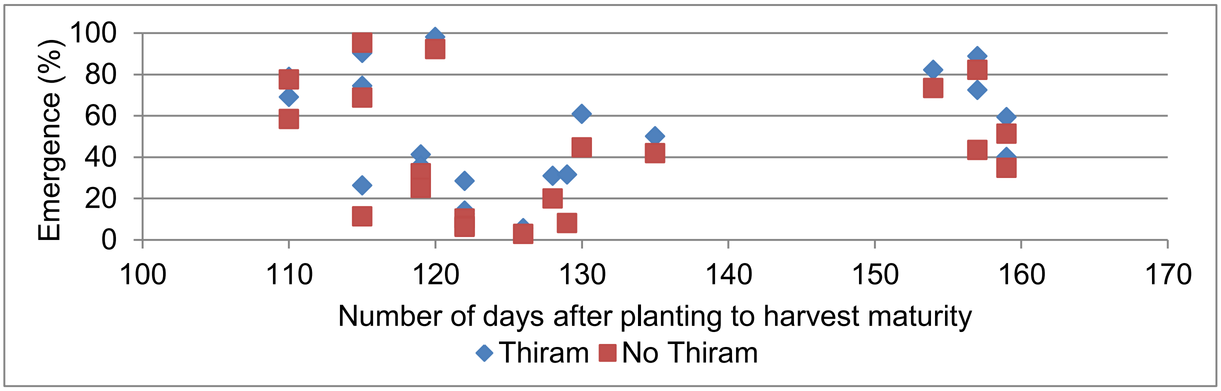

FIGURE 6.1 Percentage emergence of the various cultivars in the 2011/12 season relative to the number of days taken from planting to harvest maturity in the 2010/11 season

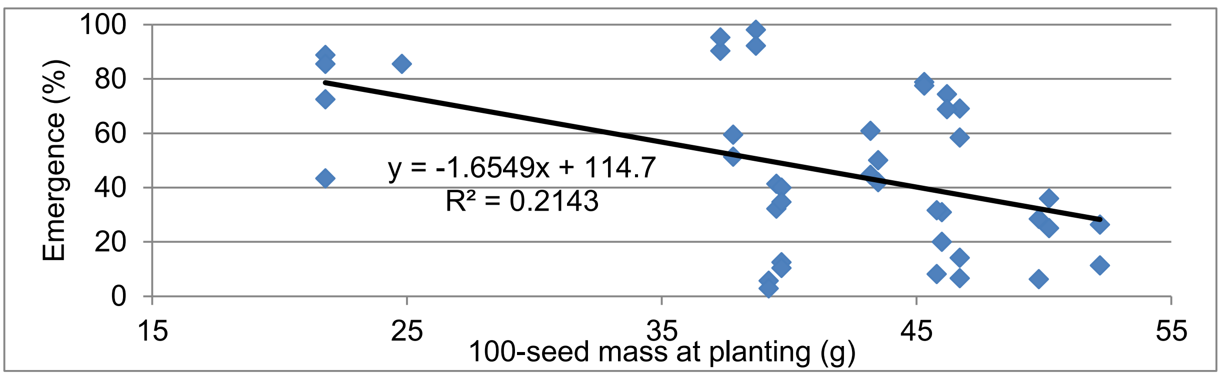

FIGURE 6.2 Percentage emergence relative to 100-seed mass at planting

TABLE 6.3 Emergence, plant height, bottom pod height, 100-seed mass and yield for the two treatments

Treatment	**Emergence (%)**	**Plant height (cm)**	**Bottom pod height (cm)**	**100-seed mass (g)**	**Yield (kg ha^{-1})**
Thiram	52.0 a	66.4 a	12.3	37.9 b	2 232 a
No thiram	42.2 b	62.3 b	11.9	39.5 a	1 985 b
Mean	**47.1**	**64.4**	**12.1**	**38.7**	**2 108**
F value	31.74	19.16	0.63	6.49	4.73
P value	**	**	NS	*	*
LSD (P<0.05)	3.61	1.96	1.16	1.36	236.8
CV (%)	11.9	4.7	14.9	5.5	17.4

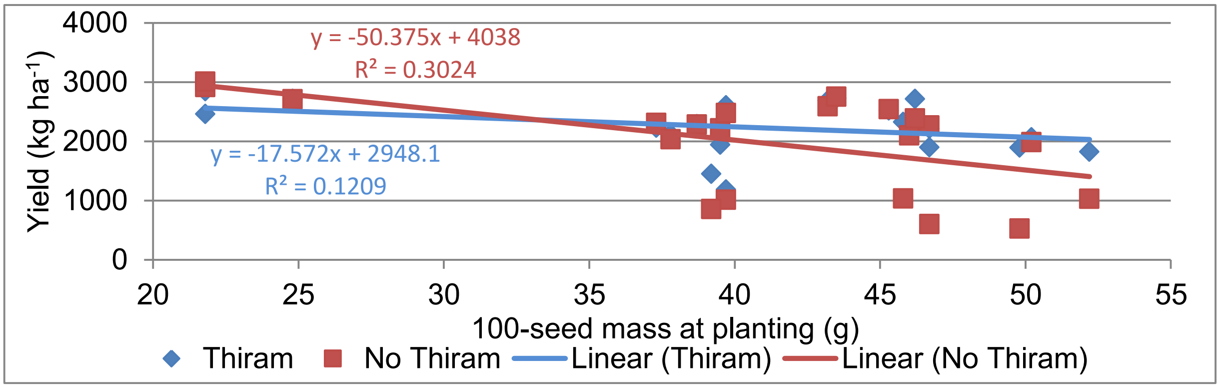

FIGURE 6.3 Effect of 100-seed mass at planting on yield

6.4.1.3 Correlations

Correlation coefficients were measured with seed yield and the yield components (Table 6.4).

TABLE 6.4 Correlation coefficients for five agronomic characteristics measured for twenty one vegetable soybean cultivars and two fungicide treatments

	Yield (kg)	100-seed mass at planting (g)	Emergence (%)	Plant height (cm)
100-seed mass at planting (g)	- 0.451 **	-	-	-
Emergence (%)	0.731 **	- 0.472 **	-	-
Plant height (cm)	0.565 **	- 0.700 **	0.359 *	-
Bottom pod height (cm)	0.593 **	- 0.506 **	0.425 **	0.811 **

Boxes highlighted in green and red are positively and negatively significant, respectively.

6.4.2 EXPERIMENT

6.4.2.1 Climatic conditions

Total rainfall received in the 2013/14 season was higher than the total received in the 2012/13 season and the long-term mean due to 240 mm of rain being received in March 2014 (Table 6.5). In March 2013, 73 mm of rain was received, whilst in April 2013 considerably more rain was received than the long-term mean and in April 2014. In both seasons the maximum and minimum mean monthly temperatures were warmer than the long-term mean from January to March, especially in the 2013/14 season (Table 6.6).

TABLE 6.5 Rainfall received at Cedara Research Station during the six month growing period in the 2012/13 and 2013/14 seasons

Month	Season 2012/13 (mm)	Season 2013/14 (mm)	Long-term mean* (mm)
November	106	105	112
December	121	138	130
January	123	98	135
February	131	96	121
March	73	240	110
April	109	17	51
Total	**663**	**694**	**659**

*93 years" data (Source: ARC-ISCW). The figures highlighted in green and red indicate months with considerably higher or lower rainfall than the long-term mean, respectively.

TABLE 6.6 Maximum and minimum temperatures measured at Cedara Research Station during the six month growing period in the 2012/13 and 2013/14 seasons

	Maximum temperature			Minimum temperature		
	Season		Long-term	Season		Long-term
	2012/13	2013/14	mean*	2012/13	2013/14	mean*
Month	(°C)		(°C)	(°C)		(°C)
November	22.7	25.5	23.6	12.3	12.5	12.4
December	26.3	24.0	24.8	14.9	13.6	12.6
January	26.7	27.7	25.1	15.3	15.6	13.6
February	27.2	28.2	24.9	14.8	15.7	13.5
March	25.0	26.3	23.9	14.0	14.0	11.9
April	23.7	24.1	22.9	9.6	9.3	10.6

*93 years" data (Source: ARC-ISCW). The figures highlighted in red indicate months with considerably warmer mean maximum temperatures than the long-term mean.

6.4.2.2 Growth stages

AGS 353 and AGS 354, which have medium growing-season lengths, reached 50% flowering 56 days after planting (DAP), whilst AGS 352 and Lightning, which are long-season cultivars, reached 50% flowering 70 and 71 DAP, respectively. AGS 353 and AGS 354 were harvested at maturity 132 and 133 DAP, respectively. AGS 352 and Lightning were harvested 146 and 151 DAP, respectively.

6.4.2.3 Plant population

A significant interaction was measured for plant population ha^{-1} with the fungicide treatments and the seasons (Table 6.7). Plant population ha^{-1} was significantly higher with all the fungicide treatments in the 2012/13 season than in the 2013/14 season (Figure 6.4). No significant differences in plant population were measured as a result of the fungicide treatments in the 2012/13 season. However, in the 2013/14 season the application of thiram resulted in a significantly higher plant population ha^{-1} than the application of Eco-T® and the control treatment, whilst captan had a significantly higher plant population ha^{-1} than Eco-T®. Thiram and captan had significantly higher mean plant populations than Eco-T® and the control treatment, between which there was no significant difference.

A significant interaction was measured for plant population ha^{-1} with the cultivars and the two seasons (Table 6.7). All the cultivars recorded significantly higher plant populations in the 2012/13 season than in the 2013/14 season (Figure 6.5). AGS 352 had a significantly lower plant population than the other three cultivars in the 2012/13 season. In the 2013/14 season Lightning recorded a significantly higher plant population than the other three cultivars, but the population was not significantly different to that recorded for AGS 352 in the 2012/13 season. AGS 353 had a significantly lower plant population than AGS 352 in the 2013/14 season.

Significant negative correlations were measured between plant population and yield, percentage active nodules, plant height, bottom pod height and 100-seed mass, whilst significant positive correlations were measured between plant population and number of nodules $plant^{-1}$ and nodule mass $plant^{-1}$ (Table 6.16).

TABLE 6.7 ANOVA table of plant population ha^{-1} for the four cultivars and the four fungicide treatments in the two trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	106.56	**	9691.5	-
Fungicide	14.92	**	4190.0	-
Cultivar	36.97	**	4190.0	-
Season x fungicide	4.50	**	9753.4	-
Season x cultivar	46.67	**	9753.4	-
Fungicide x cultivar	1.29	NS	8380.0	-
Season x fungicide x cultivar	1.17	NS	13635.1	6.7

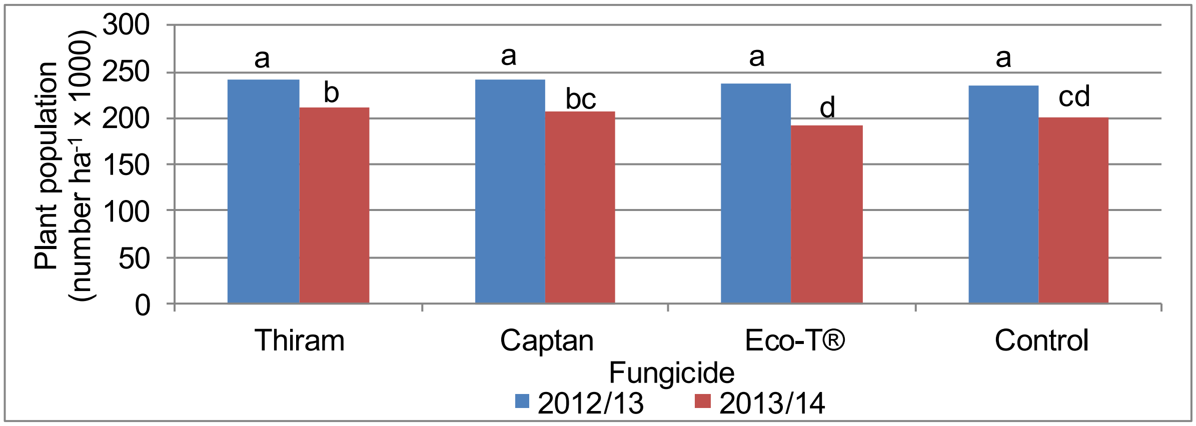

FIGURE 6.4 Plant population ha^{-1} with the four fungicide treatments in the two seasons

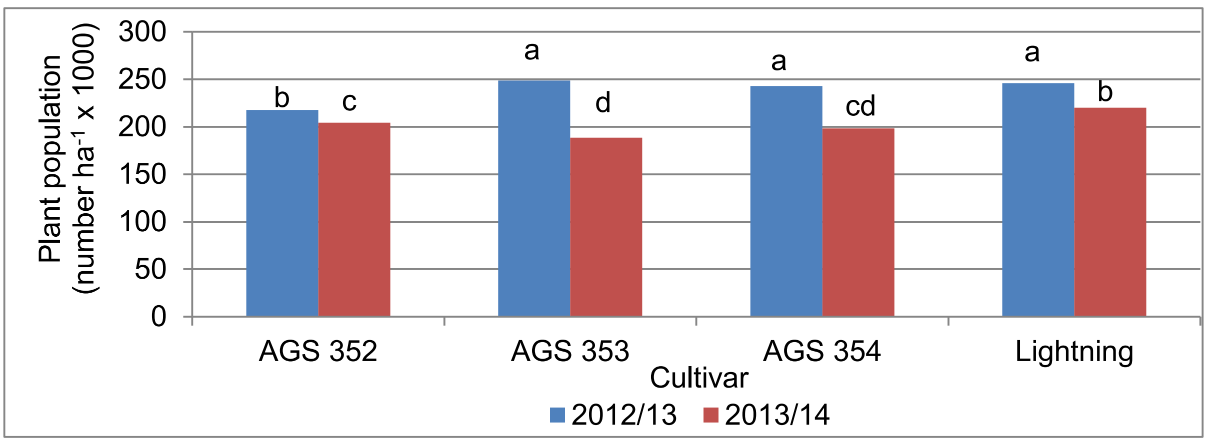

FIGURE 6.5 Plant population ha^{-1} with the four cultivars and the two seasons

6.4.2.4 Plant height

A significant interaction was measured for plant height with the cultivars and seasons (Table 6.8 and Figure 6.6). The plants of all four cultivars were significantly taller in the 2013/14 season than in the 2012/13 season. AGS 352 and Lightning produced significantly taller plants than AGS 353 and AGS 354.

No significant interaction was measured for plant height with the fungicide treatments and seasons. However, in the 2013/14 season the plants were significantly taller after thiram and captan than after Eco-T® (Table 6.9). Significantly shorter plants were measured in the control plots than in the thiram plots.

Plant height was significantly positively correlated to yield, bottom pod height and percentage active nodules, but negatively correlated to plant population and nodule mass plant^{-1} (Table 6.16).

TABLE 6.8 ANOVA table of plant height for the four cultivars and the four fungicide treatments in the two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	178.42	**	2.52	-
Fungicide	2.44	NS	1.38	-
Cultivar	359.81	**	1.38	-
Season x fungicide	1.53	NS	2.68	-
Season x cultivar	7.81	**	2.68	-
Fungicide x cultivar	0.84	NS	2.77	-
Season x fungicide x cultivar	0.85	NS	5.53	5.7

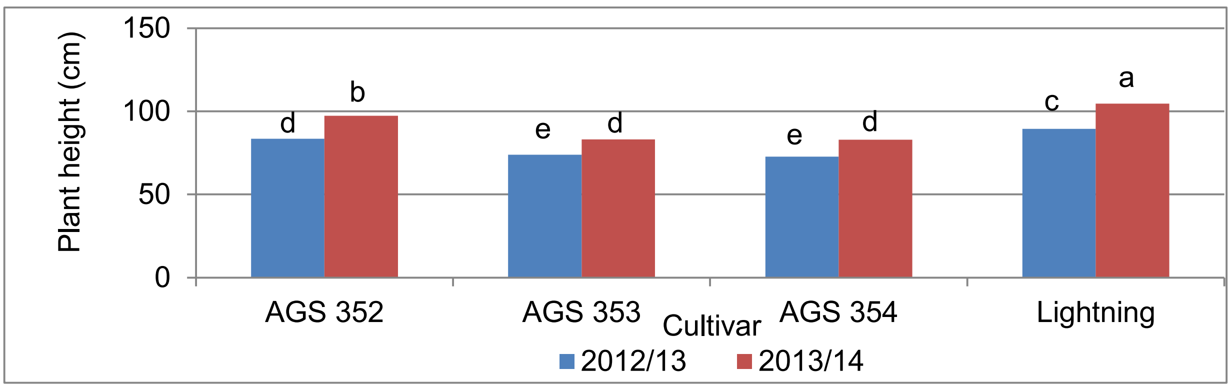

FIGURE 6.6 Plant height for the cultivars and seasons

TABLE 9 Plant height for the four fungicide treatments in the two seasons

Fungicide	Season 2012/13	2013/14 (cm)	Mean
Thiram	80.1	93.5 a	86.8
Captan	80.5	92.5 ab	86.5
Eco-T®	80.2	90.7 c	85.5
Control	78.9	91.4 bc	85.2
Mean	**79.9**	**92.0**	**86.0**
F value	0.64	6.61	1.53
P value	NS	*	NS
LSD (P<0.05)	2.46	1.32	2.68
CV %	7.6	3.5	5.7

6.4.2.5 Bottom pod height

A significant interaction was measured for bottom pod height with the cultivars and seasons (Table 6.10 and Figure 6.7). AGS 352, AGS 353 and AGS 354 had significantly higher bottom pod heights in the 2013/14 season than in the 2012/13 season. Lightning and AGS 352 had significantly higher bottom pod heights than the other cultivars in the 2012/13 and 2013/14 seasons, respectively.

Bottom pod height was significantly positively correlated to yield, plant height and percentage active nodules, but significantly negatively correlated to plant population and nodule mass $plant^{-1}$ (Table 6.16).

TABLE 6.10 ANOVA table of bottom pod height for the four cultivars and the four fungicide treatments in the two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	85.05	**	0.66	-
Fungicide	0.61	NS	0.63	-
Cultivar	9.87	**	0.63	-
Season x fungicide	0.40	NS	0.92	-
Season x cultivar	17.72	**	0.92	-
Fungicide x cultivar	1.84	NS	1.26	-
Season x fungicide x cultivar	0.55	NS	1.78	11.4

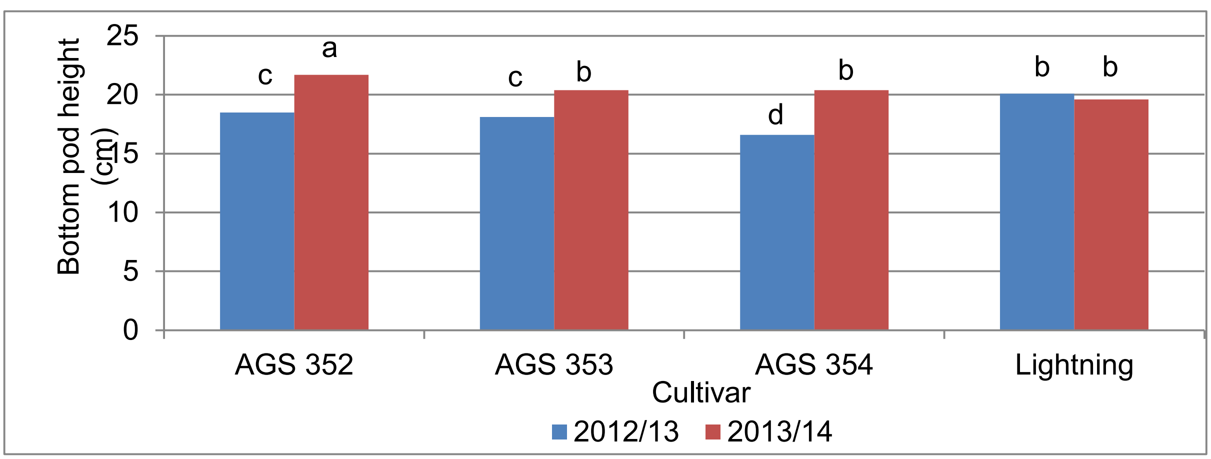

FIGURE 6.7 Bottom pod height for the cultivars and seasons

6.4.2.6 Seed mass

No significant interactions were measured for 100-seed mass between the seasons, fungicides and cultivars. However, AGS 353 (44.3 g) and AGS 354 (44.7 g) had significantly higher mean

100-seed masses than AGS 352 (29.6 g) and Lightning (25.8 g), between which a significant difference was measured.

100-seed mass was significantly positively correlated to yield and plant height, but significantly negatively correlated to plant population and nodule mass plant^{-1} (Table 6.16).

6.4.2.7 Nodulation

AGS 353 was used to determine nodule number plant^{-1} in both seasons. Mean nodule number plant^{-1} was significantly higher in the 2012/13 season than in the 2013/14 season (Table 6.11). In the 2012/13 season the control treatment had significantly more nodules plant^{-1} than thiram and captan, but no significant differences were measured among the fungicide treatments in the 2013/14 season and among the means of the fungicide treatments for the two seasons.

In the 2013/14 season nodules were collected from all four cultivars. Lightning had significantly more and larger nodules, but a significantly lower percentage of active (pink) nodules than the other cultivars (Table 6.12). No significant interaction was measured with the fungicides and cultivars for all these characteristics.

A significantly higher mean percentage of active nodules were measured in the 2013/14 season than in the 2012/13 season for AGS 353 (Table 6.13). However, no significant differences were measured for percentage active nodules resulting from the fungicide treatments in both seasons. No significant interactions were measured with the seasons and fungicide treatments for percentage active nodules and nodule mass plant^{-1}.

Nodule mass plant^{-1} was significantly positively correlated to plant population and number of nodules plant^{-1}, but significantly negatively correlated to yield, percentage active nodules, plant height, bottom pod height and 100-seed mass (Table 6.16).

TABLE 6.11 Nodules plant^{-1} for the various fungicide treatments in the 2012/13 and 2013/14 seasons for the cultivar AGS 353

Fungicide	Season 2012/13	2013/14 (number plant^{-1})	Mean
Thiram	56.1 b	28.0	42.0
Captan	55.0 b	37.5	46.2
Eco-T®	59.5 ab	35.9	47.7
Control	63.5 a	31.7	47.6
Mean	**58.5 x**	**33.3 y**	**45.9**
F value	3.45	1.62	1.82
P value	*	NS	NS
LSD (P<0.05)	5.97	9.73	5.59
CV %	12.2	35.1	21.1

TABLE 6.12 Nodule number and mass and percentage active nodules for the four cultivars in the 2013/14 season

Cultivar	Nodules (number plant^{-1})	Nodule mass (g plant^{-1})	100-nodule mass (g)	Active nodules (%)
AGS 352	31.1 b	0.89 b	2.86 b	88.7 b
AGS 353	33.3 b	0.87 b	2.72 b	95.7 a
AGS 354	29.5 b	0.81 b	2.70 b	95.5 a
Lightning	37.9 a	1.34 a	3.58 a	83.3 c
Mean	**32.9**	**0.98**	**2.97**	**90.8**
F value	5.32	23.73	18.41	40.4
P value	**	**	**	**
LSD (P<0.05)	4.44	0.14	0.27	2.63
CV %	33.3	35.7	22.7	7.2

TABLE 6.13 Percentage active nodules for the various fungicide treatments in the 2012/13 and 2013/14 seasons for the cultivar AGS 353

Fungicide	Season 2012/13	2013/14 (%)	Mean
Thiram	80.8	95.2	88.0
Captan	79.4	95.0	87.2
Eco-T®	76.5	97.3	86.9
Control	82.9	95.2	89.1
Mean	**79.9 b**	**95.7 a**	**87.8**
F value	0.58	2.34	0.27
P value	NS	NS	NS
LSD (P<0.05)	10.28	2.63	8.13
CV %	15.4	7.2	10.6

6.4.2.8 Yield

A significant interaction was measured for yield with the cultivars and seasons (Table 6.14 and Figure 6.8). No significant differences in yield were measured among the cultivars in the 2013/14 season, but the yields were significantly higher than those obtained by all the cultivars in the 2012/13 season. AGS 352 produced a significantly higher yield than Lightning in the 2012/13 season and a significantly higher mean yield than AGS 353 and Lightning, between which a significant difference was measured.

No significant interaction was measured for yield with the seasons and the fungicide treatments. No significant differences were measured for yield among the fungicide treatments in the 2012/13 season and in the mean yields for the two seasons (Table 6.15). However, in the 2013/14 season, thiram and the Control treatment recorded significantly higher seed yields than captan. A significantly higher mean yield was produced in the 2013/14 season than in the 2012/13 season due to the abundant rainfall received in March 2014.

Yield was significantly and positively correlated to percentage active nodules, plant height, bottom pod height and 100-seed mass, but significantly negatively correlated to plant population and nodule mass plant^{-1} (Table 6.16).

TABLE 6.14 ANOVA table of yield for the four cultivars and the four fungicide treatments in the two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	27.60	**	264.0	-
Fungicide	2.50	NS	72.5	-
Cultivar	11.63	**	72.5	-
Season x fungicide	0.79	NS	257.5	-
Season x cultivar	4.31	**	257.5	-
Fungicide x cultivar	0.68	NS	145.0	-
Season x fungicide x cultivar	1.57	NS	291.5	7.6

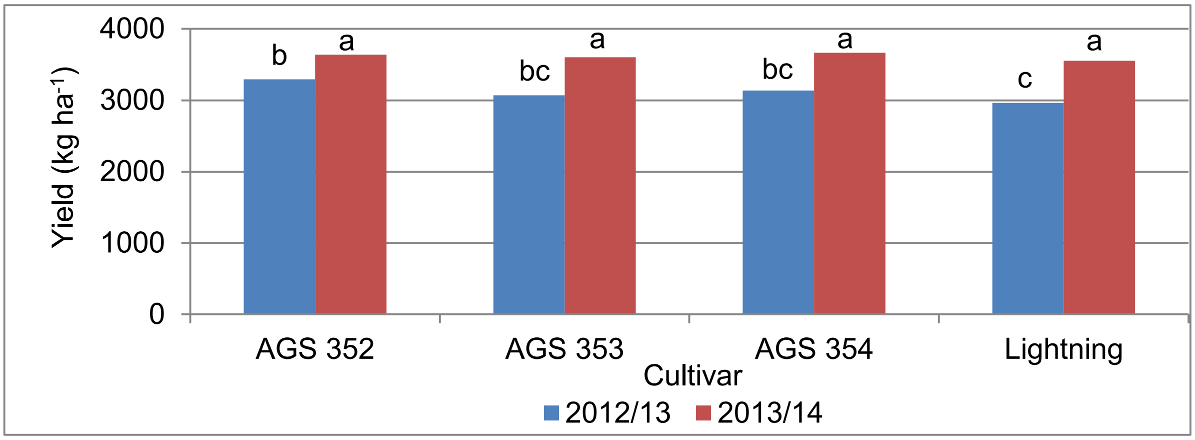

FIGURE 6.8 Seed yield for the cultivars and seasons

TABLE 6.15 Yield of the four fungicide treatments in the two seasons

Fungicide	Season 2012/13	2013/14 (kg ha^{-1})	Mean
Thiram	3 138	3 672 x	3 405
Captan	3 072	3 545 y	3 308
Eco-T®	3 149	3 597 xy	3 373
Control	3 108	3 651 x	3 379
Mean	**3 117 b**	**3 616 a**	**3 367**
F value	0.78	2.79	0.79
P value	NS	*	NS
LSD (P<0.05)	109.9	95.6	72.5
CV %	8.7	6.5	7.6

6.4.2.9 Correlations

The correlations coefficients measured between the various agronomic characteristics observed with AGS 353 over the two seasons are recorded in Table 6.16.

TABLE 6.16 Correlation coefficients of various agronomic characteristics measured for AGS 353 and pooled over two seasons

	Yield (kg ha^{-1})	Plant population ha^{-1}	Nodules $plant^{-1}$	Nodule mass $plant^{-1}$	Active nodules (%)	Plant height (cm)	Bottom pod height (cm)
Plant population ha^{-1}	-0.573 **	-	-	-	-	-	-
Nodules $plant^{-1}$	-0.125 NS	0.631 **	-	-	-	-	-
Nodule mass $plant^{-1}$ (g)	-0.486 **	0.593 **	0.527 **	-	-	-	-
Active nodules (%)	0.368 **	-0.634 **	-0.017 NS	-0.440 **	-	-	-
Plant height (cm)	0.411 **	-0.512 **	-0.191 NS	-0.425 **	0.328 **	-	-
Bottom pod height (cm)	0.267 **	-0.342 **	-0.060 NS	-0.234 *	0.263 **	0.227 *	-
100-seed mass (g)	0.339 **	-0.286 **	-0.130 NS	-0.455 **	0.040 NS	0.230 *	-0.011 NS

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

TABLE 6.17 Soil analytical results from the sites used in the 2012/13 and 2013/14 season

Season	P	K	Ca	Mg	Exch. acidity	Total cations	Acid sat.	pH (KCl)	Zn	Mn	Cu	Organic C	N	Clay
	(mg/L)				(cmol/L)		(%)		(mg/L)			(%)		
2012/13	12	162	1092	203	0.22	7.75	3	4.52	4.0	6	4.7	3.1	0.23	43
2013/14	17	86	1052	155	0.31	7.06	4	4.45	4.4	5	5.6	2.6	0.18	44

6.5 DISCUSSION

Phomopsis seed decay (PSD) of soybean is caused primarily by the pathogen *Phomopsis longicolla* Hobbs along with other *Phomopsis* and *Diaporthe* species. The disease causes poor seed quality, which results in poor plant stands and yield (Li and Chen, 2013). Hot and humid environmental conditions, especially during the period from pod-fill to harvest maturity, favour pathogen growth and disease development (Gleekia-Kerkula, 2012; Liebenberg, 2012; Li and Chen, 2013). The hot and wet conditions experienced at Cedara during March and April 2011 (Tables 1 and 2) resulted in *Phomopsis* infection of the pods and seed. The range in percentage emergence was 4.2% to 95.2%, with the cultivars that matured at 119 to 129 DAP being most affected (Figure 6.1). Li *et al*. (2011) reported up to 80% *Phomopsis* seed infection following a season with hot and humid conditions from pod-fill to harvest maturity. However, the authors identified some cultivars with good resistance to PSD in that season. In the demonstration trial the brown-seeded cultivars, AGS 457 and AGS 458, had above 92% emergence and therefore could be resistant to PSD. However, a full investigation will have to be undertaken to determine if these two cultivars are resistant to PSD.

The early and late maturing cultivars were less affected by PSD (Figure 6.1). Within the late maturing cultivars, higher percentage emergence was obtained by the small-seeded cultivars, AGS 352 and Lightning, than the large black-seeded cultivars, Tanba and Tanbaguro. The significant negative correlation measured between seed size and emergence (Figure 6.2 and Table 6.4) confirmed the results obtained by Khalil *et al*. (2001), who reported that germination was inversely related to seed size and temperature.

Researchers suggest planting soybean for seed production late in the season to avoid wet, and hot conditions, which may lead to pod infection (Khalil *et al.*, 2001; Egli *et al.*, 2005; Ren *et al*., 2009; Khan *et al.*, 2011; Liebenberg, 2012). Yan *et al.* (2001) stated that seed production locality should have maximum temperatures from 25°C - 30°C with low relative humidity. Studies in Taiwan (Chen *et al.*, 1991) and Pakistan (Khalil *et al*., 2001) established that autumn was the best season for seed production since the temperature is moderate, the relative humidity is low and there is a prolonged dry period. Sharma (2013) stated that when seed was harvested in dry conditions, improved seedling emergence occurred. Khalil *et al*. (2001) reported that germination decreased by 10.7% with every 1°C temperature increase above 30°C and decreased by 20.4% with every 1 g increase in 100-seed weight. Khan *et al*. (2011) found that an increase in mean canopy temperature in the range of 23 - 30°C from full-seed to physiological maturity (R6 - R7) improved germination and field emergence whereas an increase in temperature from seed initiation to full-seed (R5 - R6) reduced germination and field emergence. Liebenberg (2012) recommended that fungicides be applied to the plants from pod-fill to maturity to prevent pod disease infection.

The fact that seed vigor declined as seed size increased may explain to some extent why the emergence of vegetable soybean, which has very large seeds (approximately 40 g 100 seeds^{-1}) compared to grain soybean (approximately 16 g 100 seeds^{-1}), is often well below 80%, as reported by Duppong and Hatterman-Valenti (2005), Sanchez *et al*. (2005) and Hamilton (2007). Shelar *et al*. (2008) reported that seed deterioration rate and the ability to maintain seed longevity were genetically controlled, whilst cultivars with high oil contents usually had lower quality. The authors also observed that storability was superior with smaller seeds than larger seeds. Miles and Sonde (2002) and Liebenberg (2012) recommended that certified, fresh seed be planted.

Li and Chen (2013) reported that *Phomopsis* infected seeds are often symptomless. Despite selecting visibly „dean‟ seed to plant the demonstration trial, the effect of *Phomopsis* seed contamination on emergence was evident. The use of thiram as a seed dressing significantly improved emergence and consequently yield (Table 6.3). Xue *et al*. (2006) reported that the use of thiram was effective in protecting soybean from *Rhizoctonia solani* Khun and improved emergence and yield. A significant positive correlation was measured between plant population and yield, but a negative correlation was measured between plant population and 100-seed mass (Table 6.4). Seed size is genetically determined, but influenced by growing conditions (Duppong and Hatterman-Valenti, 2005; Carson *et al*., 2011). James (2007) reported that the seed size of the cultivar, C784, was not affected by seeding rates from 50 000 to 200 000 seeds ha^{-1}, but seed size generally decreased linearly from 50 000 to 400 000 seeds ha^{-1}.

Mean plant height, bottom pod height and seed yield increased significantly with the higher plant populations, which resulted from the application of thiram, whilst 100-seed mass was significantly lower (Table 6.3). Christmas (2008) and Epler and Staggenborg (2008) reported a similar relationship with plant height, bottom pod height and plant population. The low mean yield of 2.1 t ha^{-1} was due to the low rainfall and warm conditions experienced in February and March 2012 (Tables 6.1 and 6.2).

The mean plant population was 89.6% and 76.1% of the seeding rate in the 2012/13 and 2013/14 seasons, respectively. Significant interactions were measured for plant population with the fungicide treatments and seasons and with the cultivars and seasons (Table 6.7; Figures 6.4 and 6.5). In the 2012/13 season plant population was significantly higher as a result of all the fungicide treatments than in the 2013/14 season (Figure 6.4). In the 2013/14 season the application of thiram resulted in a significantly higher plant population than Eco-T® and the Control treatment, whilst captan caused a significantly higher plant population than Eco-T®. Overall, the application of thiram and captan resulted in significantly higher plant populations than Eco-T® and the Control treatment, indicating that these fungicides provided better control against seed-borne and soil-borne pathogens. In the 2012/13 season, AGS 352, a small-seeded cultivar, had a significantly lower plant population than the other three cultivars, among which no significant differences were measured (Figure 6.5). However, in the 2013/14 season, the small-seeded cultivar, Lightning, had a significantly higher plant population than the other cultivars, whilst the large-seeded cultivar, AGS 353, had the lowest plant population. Khalil *et al*. (2001) reported that germination decreased as seed size increased. Variations in plant population among vegetable soybean cultivars and the seasons were reported by Duppong and Hatterman-Valenti (2005), Sanchez *et al*. (2005) and Hamilton (2007).

Despite a lower mean plant population in the 2013/14 season, all the cultivars had significantly taller plants (Figure 6.6) and higher bottom pod heights (Figure 6.7), except for Lightning, than in the 2012/13 season. Plant height and bottom pod height usually increase as plant population increases (Christmas, 2008; Epler and Staggenborg, 2008), but negative correlations were measured between plant population and the plant and bottom pod heights (Table 6.16). Higher rainfall received in December 2013 than in December 2012 may have resulted in greater vegetative growth in the 2013/14 season (Table 6.5). However, due to significantly higher plant populations, thiram and captan treatments resulted in taller plants than Eco-T® and the Control treatments (Table 6.9). The variations in plant height and bottom pod height among the cultivars were due to growing-season length (Hamilton, 2007; Zhang and Kyei-Boahen, 2007; Swathi, 2009). AGS 353 and AGS 354 had shorter growing–seasons than AGS 352 and Lightning and therefore had shorter plants. AGS 353 and AGS 354 had significantly higher 100-seed masses than AGS 352 and Lightning. This yield component is genetically determined and is not related to growing–season length, but is influenced by the growing conditions (Duppong and Hatterman-Valenti, 2005; Carson *et al*., 2011).

Andrés *et al*. (1998), Campo *et al*. (2009) and Liebenberg (2012) reported conflicting results of thiram and captan on nodulation. In the 2012/13 season, but not in the 2013/14 season and overall, the application of thiram and captan resulted in significantly lower numbers of nodules plant^{-1} than Eco-T® and the Control treatments (Table 6.11), but nodule mass per plant and percentage active nodules were not affected. The mean number of nodules plant^{-1} were significantly lower in the 2013/14 season than in the 2012/13 season, but the mean percentage active nodules were significantly higher (Table 6.16). Although soybean had not been grown on either site within the previous ten years, it is possible that *Rhizobial* populations were present and in higher numbers in the 2012/13 site. Under favourable conditions, nodulating bacteria can remain in the soil for several years (Liebenberg, 2012). The environment has a profound impact on nodulation. High temperatures, drought, soil acidity (Hungria and Vargas, 2000) and water-logging (Amarante and Sodek, 2006) will reduce nodule formation and function. The drier and warm conditions experienced in January and February 2014 may have resulted in the lower mean number of nodules plant^{-1} in the 2013/14 season than in the 2012/13 season (Tables 6.5 and 6.6). Liebenberg (2012) reported that nodulation can be reduced with pH levels below 5.2. Soil pH in the two seasons was 4.52 and 4.45 (Table 6.17).

Lightning had a significantly higher number of nodules plant^{-1}, which were significantly larger than those of the other cultivars, but the percentage active nodules was significantly lower (Table 6.12). Nodulation differences have been reported among soybean cultivars (Salvucci *et al.*, 2012; Solomon *et al.*, 2012). Salvucci *et al.* (2012) reported that cultivar growing-season length had no effect on cultivar nodulation ability.

Despite higher plant populations being obtained with the application of thiram and captan, no significant increase in yield was measured. This result could be due to the plants in the Eco-T® and Control treatments compensating for lower plant populations by producing more pods plant^{-1} (Haifeng, 2006; Sharma, 2013). Zilli *et al.* (2009) reported that yield was not affected by a significant reduction (> 50%) in nodule number plant^{-1} with the application of carbendazim + thiram. However, Campo *et al*. (2009) reported that nodule number plant^{-1} and yield were significantly reduced with the application of thiram and captan and that the effect was greater when the crop was grown in sandy soils. The clay content of the soil in the experiment at Cedara was 43% and 44% for the two sites. The number and mass of nodules plant^{-1} had a significant negative correlation with yield, whilst the percentage active nodules had a significant positive correlation with yield (Table 6.15).

Trichoderma strains have been documented as having important plant growth promoting properties, such as enhancing germination and shoot and root growth, in addition to bio-controlling soil-borne pathogens (Olabiyi *et al.*, 2013; Tančić *et al*., 2013). However, the application of *harzianum* as Eco-T® did not improve plant population, nodule number plant^{-1}, percentage active nodules and yield above the Control treatment. Plant height, bottom pod height and 100-seed mass were also not increased. The soil fertility and growing conditions in the experiment may have been ideal and therefore Eco-T® had no effect. However, in poor fertility soils, Abudulai *et al*. (2014), reported significant increases in yield when Eco-T® was used, especially when co-inoculated with *Bradyrhizobium japonicum*.

Despite a lower plant population and nodule number plant^{-1} in the 2013/14 season than in the 2012/13 season, the yields were significantly higher, as a result of the higher rainfall received during pod-fill. Therefore, the quantity of rainfall had a greater effect on yield than plant population and nodulation.

Although the applications of thiram and captan resulted in significantly higher plant populations than the application of Eco-T® and the Control treatment, no significant yield benefit was obtained and therefore it can be concluded that the application of these fungicides as seed coatings at planting were unnecessary. However, it may be beneficial to apply fungicides if the seed quality is suspected to be poor or if the land has a known history of diseases.

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CHAPTER 7

THE EFFECT OF THREE *BRADYRHIZOBIUM JAPONICUM* INOCULANTS ON THE GROWTH, NODULATION AND PRODUCTION OF FOUR VEGETABLE SOYBEAN CULTIVARS

7.1 ABSTRACT

Vegetable soybean (*Glycine max* (L.) Merrill), edamame, is poorly known in South Africa, but this high-protein crop could be suitable for small-scale and commercial farmer production. The seeds are larger, milder-tasting and more tender than grain soybeans. The pods are picked green when the beans have filled 80 to 90% of the pod. The beans are eaten like green peas. Two field trials were conducted in the 2012/13 and 2013/14 seasons at the Cedara Research Station and one in the 2013/14 season at the Dundee Research Station, KwaZulu-Natal, South Africa using a randomized complete blocks design with three replicates. The objective was to evaluate three commercially available *Bradyrhizobium japonicum* Kirchner inoculants, Soycap, Eco-Rhizsoy® and Hi-stick®, against a control treatment (no inoculation) on the nodulation and yield of four vegetable soybean cultivars, AGS 352, AGS 353, AGS 354 and Lightning. At Cedara a significantly higher percentage of active nodules plant^{-1} and a significantly higher seed yield were measured in the 2013/14 season compared to the 2012/13 season, due to more rainfall being received during pod-fill. Overall, no significant differences were measured between the inoculant treatments for plant population, plant height, 100-seed mass, percentage leaf nitrogen at flowering, nodule number plant^{-1}, nodule mass plant^{-1} and percentage active nodules. At Cedara the application of Soycap and Eco-Rhizsoy® resulted in significantly higher mean yields than the Control, whilst at Dundee no significant differences in yield were measured between the inoculant treatments. In all three experiments yield was significantly positively correlated to percentage leaf N at flowering, but nodule number plant^{-1} and nodule mass plant^{-1} were not significantly positively correlated to yield. At Cedara, Lightning produced a significantly lower mean yield when not inoculated with *Rhizobia* and, overall, a significantly lower mean yield than the other cultivars. AGS 352 produced a significantly higher mean yield than AGS 353. However, at Dundee, Lightning produced a significantly higher mean yield than the other cultivars.

Key words: vegetable soybean, inoculants, nodules, yield

7.2 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill), also known as edamame, is a speciality crop produced for human consumption as a green bean. The green pods are harvested at the R6 growth stage when the seeds have filled 80 – 90% of the pods and are almost touching each other (Duppong and Hatterman-Valenti, 2005; Hamilton, 2007). The beans are larger, more tender, have a nuttier flavour and are more digestible than grain soybean (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007).

Soybean is a legume and therefore has the ability to convert atmospheric nitrogen into an accessible form of nitrogen when grown in a symbiotic relationship with *Rhizobium.* This process is known as biological nitrogen fixation. The quantity of nitrogen produced can be sufficient for the plant to produce optimally, provided that the correct inoculant is used, successful nodulation occurs and the environmental conditions are ideal. Abendroth *et al*. (2006) estimated that the nitrogen requirement of soybean could be as high as 350 kg ha^{-1}.

Dry soils and high soil temperatures will destroy the *Rhizobia* (Hungria and Vargas, 2000), as will waterlogging (Amarante and Sodek, 2006). Poor nodulation will occur in soils with a pH below 5.2 (Liebenberg, 2012) and in soils with low phosphorous (P) (Kumaga and Ofori, 2004; Zarrin *et al.*, 2007; Bekere and Hailemariam, 2012) and potassium (K) (Imas *et al*., 2007). The application of agrochemicals, fungicides and micronutrients to the seed can negatively affect nodulation (Campo *et al.*, 2010).

In South Africa a bacterial strain of *Bradyrhizobium japonicum* Kirchner, WB 74, is used. It is not indigenous to South African soils and therefore inoculation must take place at planting either as a peat coating on the seed or sprayed as a liquid into the planting furrow. Inoculation is very cost effective in relation to the cost of applying expensive nitrogen fertilizers. In lands that have never been planted to soybean, inoculation is essential. In subsequent seasons inoculation may not be necessary because the *Rhizobia* can remain in the soil for many years (Liebenberg, 2012). Some research studies have reported yield increases with successive inoculant applications, whilst others have reported no yield increase (Conley and Christmas, 2006; Pedersen, 2007; Campo *et al*., 2010; Wright, 2010). However, as the cost of the inoculant is low (R146-00 per 400 g sachet, which is sufficient for 100 kg of seed), regular inoculation is advised to maintain a high soil rhizobial population. The application of nitrogen fertilizer would therefore be an unnecessary cost and, if applied, may even reduce nodulation and subsequently yields (Campo *et al*., 2010), unless the soil clay content is below 10% (Liebenberg, 2012). Emam and Rady (2014) reported that the application of 60 kg ha^{-1} N together with *B. japonicum* inoculation resulted in more nodules, higher nodule mass and greater soybean yields than when *B. japonicum* was applied alone to soybean grown in a soil with 11% clay. The authors reported that no nodules were detected on uninoculated plants and when 180 kg ha^{-1} N was applied, indicating that very high levels of N were extremely detrimental to nodulation.

The soybean plant"s demand for nitrogen is highest from the R5 to the R8 reproductive growth stages (Pedersen, 2007). Lamptey *et al*. (2014) reported that nodule formation and nodule biomass were greatest at the full-pod stage.

Residual biological nitrogen from a soybean crop can increase the yield of a subsequent maize (*Zea mays* L.) crop by up to 12% (Liebenberg, 2012) because the soybean residues leave about 40 to 60 kg N ha^{-1} in the soil, depending on the yield and degree of nodulation (Birch *et al*., 1990). Therefore, a farmer can save on nitrogen fertilizer costs by not having to apply as much N.

Variations in soybean nodule number, nodule mass and seed yield by various *B. japonicum* strains have been reported (Zarrin *et al.*, 2007; Solomon *et al.*, 2012). Interestingly, when Zarrin *et al.* (2007) applied three strains of *B. japonicum* together, a significantly higher nodule mass $plant^{-1}$ and seed mass $plant^{-1}$ was obtained than when the strains were applied individually.

Solomon *et al*. (2012) found no significant differences in nodule number $plant^{-1}$ among the grain soybean cultivars evaluated, whilst Salvucci *et al*. (2012) and Emam and Rady (2014) reported nodulation differences among the soybean cultivars. Salvucci *et al.* (2012) found that cultivar growing-season length had no effect on nodulation ability.

As vegetable soybean is a new crop in South Africa, it was felt important to evaluate three commercially available *Bradyrhizobium japonicum* inoculants on the nodulation and yield of four vegetable soybean cultivars.

7.3 MATERIALS AND METHODS

7.3.1 Sites

7.3.1.1 Cedara

A field trial was conducted over two seasons, from October 2010 to May 2013, at the Cedara Research Station of the KwaZulu-Natal Department of Agriculture and Rural Development (KZN DARD), South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The mean annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp, 1999 (a)). The climatic data for 2010 to 2013 was received from the automatic weather station of the Agricultural Research Council – Institute of Soil, Climate and Water (ARC-ISCW) on the Cedara Research Station. The soil was a Hutton form with an orthic A over a red apedal B and had a depth > 1 m. Soil analyses showed a mean of 43.5% clay and 2.9% organic carbon. The mean pH (KCl) and acid saturation during the experimental period was 4.49 and 3.5%, respectively. Soybean had not been grown on either site in the previous ten years.

7.3.1.2 Dundee

A field trial was conducted during the 2013/14 season at the Dundee Research Station of the KZN DARD, South Africa (latitude 28°13'S; longitude 30°31'E; altitude 1219 m). The mean annual rainfall is 782 mm, of which about 686 mm falls from October to April. The mean annual A-pan evaporation is 1987 mm and 6.8 hours of sunshine per day are received during October to March (Camp, 1999 (b)). The climatic data for the 2013/14 season was received from the ARC-ISCW‟s automatic weather station on the Dundee Research Station. The soil was an Avalon form with an orthic A over a yellow-brown apedal B over a soft plinthic B and had a depth > 1 m. Soil analyses showed 18% clay and 1.0% organic carbon. The pH (KCl) and acid saturation was 4.82 and 3.0%, respectively. Soybean was last grown on the site in the 2009/10 season.

7.3.2 Land preparation

The lands at Cedara and Dundee had been planted to maize and *Eragrostis curvula* Schrad in the preceding seasons, respectively. Soil samples were taken from each land during July or August of the same planting year and analyzed by the Fertilizer Advisory Services‟ Laboratories of the KZN DARD based on the Cedara Research Station.

At Cedara the lands were cultivated twice with a tractor-drawn offset disc-harrow in spring. At Dundee the land was ploughed with a mouldboard plough and disced twice with an offset disc-harrow in spring. Prior to planting a tractor-drawn konskilde was used at both sites.

7.3.3 Fertilization and planting

After tillage the rows were opened using a hand-held V-shaped hoe. Based on the results of the soil analyses (Tables 23 and 24), 20 kg P ha^{-1} was hand-applied to each row as single superphosphate (10.5% P). In the 2013/14 season at Cedara 35 kg K ha^{-1} was also applied to each row. Thereafter the fertilizer was covered with approximately 0.02 m of soil using a garden rake. The trials were planted on 28 November 2012 and 27 November 2013 at Cedara and on 26 November 2013 at Dundee. Seeds of the cultivars, AGS 352, AGS 353, AGS 354 and Lightning, were moistened with a 5% sugar-water solution and then coated with the following inoculant:

1. Soycap (Rate: 250 g / 25 kg seed (2013/14), Strain WB 74, 1 x 10^9 colony forming units/gram; Soygro[1]).
2. Eco-Rhizsoy® (Rate: 50 g / 50 kg seed, Strain WB 74; Plant Health Products[2]).
3. Hi-Stick® (400 g / 100 kg seed; minimum 4 x 10^9 viable cells of *B. japonicum* $gram^{-1}$; (Line 3 OXBG2/M4 Y091 peat based; BASF[3]).
4. Control (no inoculant applied).

At Cedara the seed was hand-planted 0.05 m apart in the 0.75 m wide rows at a seeding rate of 266 667 seeds ha^{-1}, whilst at Dundee the seed was hand-planted 0.05 m apart in the 0.7 m wide rows at a seeding rate of 285 700 seeds ha^{-1}. Each plot consisted of 4 rows of 5 m length. Immediately after placement of the seeds in the row they were covered with soil using a garden rake.

[1] Soygro (Pty) Ltd., P.O. Box 5311, Kockspark, Potchefstroom, 2523. Tel.: 018 2921907.

[2] Plant Health Products, P.O. Box 207, Nottingham Road, 3280. Tel.: 033 2666130.

[3] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

7.3.4 Pest control

S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[1]) was applied at 1189.5 and 732 g a.i. ha^{-1} at Cedara and Dundee, respectively, together with imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF) at 50 and 40 g a.i. ha^{-1}, respectively, as pre-emergence herbicides immediately after planting, using a knapsack sprayer equipped with a flat-spray nozzle. The post-emergence herbicide bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) was applied at both sites five weeks after planting at 1440 g a.i. ha^{-1} with a knap-sack sprayer fitted with a Lurmark DT 30 flat-spray nozzle.

At both sites, the insecticide, cypermethrin (Kemprin® 200 EC, 200 g a.i. L^{-1}, Arysta Life Science[2]), was applied at 400 a.i ha^{-1} with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller) and applied during the growing period to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner). Carbendazim/flusilazole (Punch C®, 125/250 g a.i. L^{-1}, Du Pont de Nemours[3]) was applied at 50/100 g a.i. ha^{-1} at flowering and again three weeks after flowering to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow) using a knapsack sprayer equipped with a Lurmark DT 30 flat-spray nozzle.

7.3.5 Data collection

On 02/01/2013 a Konica Minolta hand-held chlorophyll meter (Supplier: Narich, Cape Town) was used to take readings from six randomly selected plants in the middle two rows of each plot at Cedara. The readings were conducted on the fourth highest trifoliate leaf on each plant.

At 50% flowering thirty two randomly selected leaf samples of the highest fully expanded trifoliate leaf were taken from each plot (8 per row). At Cedara, leaves of AGS 353 and AGS 354 were sampled at 56 and 57 days after planting (DAP) in the 2012/13 and 2013/14 seasons, respectively, whilst leaves were sampled from AGS 353 and Lightning at 70 and 71 DAP, respectively. At Dundee the leaf samples were taken from AGS 353 and AGS 354 at 57 DAP and from AGS 352 and Lightning at 68 DAP. The leaves were analyzed for nitrogen content by the Plant Laboratory of the KwaZulu-Natal Department of Agriculture and Rural Development based at Cedara.

[1] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[2] Arysta Life Science, 7 Sunbury Office Park, La Lucia Ridge, 4019. Tel.: 031 514 5600.

[3] Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

At flowering six adjacent plants were randomly selected in both the first and fourth rows and dug up using a spade. The nodules were counted, dissected to determine whether they were active (pink) or inactive (white, green or brown), and weighed. In the 2012/13 season only AGS 353 was used to observe nodulation, whilst in the 2013/14 season all four cultivars were used at both Cedara and Dundee. At Cedara nodule samples were taken at 58 DAP for AGS 353 in the 2012/13 season. In the 2013/14 season nodule samples were taken from AGS 353 and AGS 354 at 68 and 69 DAP, respectively, whilst nodule samples were taken from AGS 352 and Lightning at 77 and 78 DAP, respectively. At Dundee nodule samples were taken from AGS 353 and AGS 354 at 68 DAP and from AGS 352 and Lightning at 83 DAP.

At pod maturity, plants in the middle 4 m of the two centre rows were used to determine plant height, bottom pod height, plant population ha^{-1} and yield ha^{-1}. Plant height was measured from the ground to the top of the highest positioned pod on ten plants per plot. Bottom pod height was measured from the ground to the bottom of the lowest positioned pod on the same ten plants per plot. At Cedara the plants of AGS 353 and AGS 354 were harvested on the same day at 132 and 133 DAP in the 2012/13 and 2013/14 seasons, respectively. AGS 352 and Lightning were harvested at 146 and 151 DAP in the 2012/13 and 2013/14 seasons, respectively. At Dundee AGS 353 and AGS 354 were harvested at 134 DAP, whilst AGS 352 and Lightning were harvested at 150 DAP. The plants were hand-harvested using secateurs and the pods were shelled manually. The seed was weighed and converted to 12.5% moisture content after determining the moisture content using a Sinar GrainPro 6310 Moisture Analyzer (Supplier: Ronin Grain Management Solutions, Modderfontein, South Africa). One hundred randomly selected seeds were counted and weighed to determine 100-seed mass.

7.3.6 Statistical analysis

A randomized complete blocks design with three replicates was used. The data was analyzed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al*., 2007). Treatment means were measured using Fisher‟s Protected Least Significant Difference procedure with P=0.05.

7.4 RESULTS

7.4.1 CEDARA EXPERIMENT

7.4.1.1 Climatic conditions

The total rainfall received during the 2012/13 season was similar to the long-term mean, whilst the total rainfall received in the 2013/14 season was above-average, due to the abundant rainfall received in March 2014 (Table 7.1). A severe hailstorm on 31/12/2012 resulted in considerable leaf loss**.** Below-average rainfall was received in March 2013, which coincided with grain-fill. Very little rainfall was received in April 2014, which coincided with the final stages of pod-fill for AGS 352 and Lightning. In February 2013 and from January to March 2014 the maximum temperatures were considerably warmer than the long-term mean (Table 7.2).

TABLE 7.1 Rainfall received at the Cedara Research Station during the six month growing period in the 2012/13 and 2013/14 seasons

Month	**Season 2012/13**	**Season 2013/14**	**Long-term mean***
	(mm)		
November	106	105	112
December	121	138	130
January	123	98	135
February	131	96	121
March	73	240	110
April	109	17	51
Total	**663**	**694**	**659**

*93 years" data (Source: ARC-ISCW). The figures highlighted in green and red indicate months with considerably higher or lower rainfall than the long-term mean, respectively.

TABLE 7.2 Maximum and minimum temperatures measured at the Cedara Research Station during the six month growing period in the 2012/13 and 2013/14 seasons

	Maximum			**Minimum**		
	Season			**Season**		
	2012/13	**2013/14**	**Long-term mean***	**2012/13**	**2013/14**	**Long-term mean***
Month	**(°C)**			**(°C)**		
November	22.7	25.5	23.6	12.3	12.5	12.4
December	26.3	24.0	24.9	14.9	13.6	13.9
January	26.7	27.7	25.4	15.3	15.6	14.9
February	27.2	28.2	25.4	14.8	15.7	14.9
March	25.0	26.3	24.7	14.0	14.0	13.7
April	23.8	24.0	22.9	9.4	9.3	10.6

*93 years" data (Source: ARC-ISCW). The figures highlighted in red indicate months with considerably warmer maximum temperatures than the long-term mean.

7.4.1.2 Plant population

A significant interaction for plant population ha^{-1} was measured between the four cultivars and the two seasons (Table 7.3.1). All the cultivars recorded significantly higher plant populations ha^{-1} in the 2012/13 season than in the 2013/14 season (Table 7.3.2). AGS 352 had a significantly lower plant population than the other three cultivars in the 2012/13 season. In the 2013/14 season Lightning had a significantly higher plant population ha^{-1} than the other three cultivars, but the population was not significantly different to that of AGS 352 in the 2012/13 season. AGS 353 had a significantly lower plant population ha^{-1} than AGS 352 in the 2013/14 season.

In both seasons the plant population of AGS 353 was significantly positively correlated to the number of nodules plant^{-1} and nodule mass plant^{-1}, but significantly negatively correlated to yield, plant height, bottom pod height, 100-seed mass, percentage active nodules and leaf N% (Table 7.14).

In the 2013/14 season plant population was significantly positively correlated to plant height and nodule mass plant^{-1}, but significantly negatively correlated to 100-seed mass and percentage active nodules (Table 7.15).

TABLE 7.3.1 ANOVA table of plant population for the various cultivars and inoculant treatments for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Season	106.56	**	9691.5	-
Cultivar	36.97	**	4190.0	-
Inoculant	1.00	NS	4190.0	-
Season x cultivar	46.67	**	9753.4	-
Season x inoculant	0.50	NS	9753.4	-
Cultivar x inoculant	0.60	NS	8380.0	-
Season x cultivar x inoculant	0.50	NS	13635.1	6.7

TABLE 7.3.2 Plant population ha^{-1} of the four cultivars in the two seasons

	AGS 352	**AGS 353**	**AGS 354**	**Lightning**	**Mean**
Season		**(plants ha^{-1} x 1000)**			
2012/13	217.7 b	248.8 a	243.0 a	246.1 a	**238.9 x**
2013/14	204.3 c	188.6 d	198.4 cd	220.1 b	**202.8 y**
Mean	**211.0 z**	**218.7 y**	**220.7 y**	**233.1 x**	**220.9**

7.4.1.3 Plant height

A significant interaction was measured for plant height between the seasons and cultivars (Table 7.4.1). Mean plant height was significantly higher in the 2013/14 season than in the 2012/13 season (Table 7.4.2). Lightning had significantly taller plants in both seasons than the other cultivars. AGS 353 and AGS 354 recorded significantly shorter plants than the other two cultivars in both seasons. The height of AGS 352 in the 2012/13 season was not significantly different to the height of AGS 353 and AGS 354 in the 2013/14 season. Overall, the plants were significantly taller in the 2013/14 season. No significant differences in plant height were measured as a result of the inoculants.

Plant height was significantly positively correlated to yield and bottom pod height, but significantly negatively correlated to 100-seed mass (Table 7.14).

Over both seasons, the plant height of AGS 353 was significantly positively correlated to yield, bottom pod height, 100-seed mass, percentage active nodules and leaf N%, whilst significantly negatively correlated to number of nodules plant^{-1} and nodule mass plant^{-1} (Table 7.15).

In the 2013/14 season plant height was significantly positively correlated to the number of nodules plant^{-1}, nodule mass plant^{-1} and leaf N%, but significantly negatively correlated to 100-seed mass and percentage active nodules (Table 7.16).

TABLE 7.4.1 ANOVA table of plant height for the various cultivars and inoculant treatments for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	178.42	**	2.52	-
Cultivar	359.81	**	1.38	-
Inoculant	0.16	NS	1.38	-
Season x cultivar	7.81	**	2.68	-
Season x inoculant	0.23	NS	2.68	-
Cultivar x inoculant	0.43	NS	2.77	-
Season x cultivar x inoculant	0.78	NS	4.22	5.7

TABLE 7.4.2 Plant height of the four cultivars in the two seasons

Season	AGS 352	AGS 353	AGS 354 (cm)	Lightning	Mean
2012/13	83.6 d	73.9 e	72.7 e	89.5 c	**79.9 y**
2013/14	97.3 b	83.2 d	82.9 d	104.7 a	**92.0 x**
Mean	**90.4 y**	**78.5 z**	**77.8 z**	**97.1 x**	**96.0**

7.4.1.4 Bottom pod height

A significant interaction was measured for bottom pod height between the four cultivars and two seasons (Table 7.5.1). AGS 352, AGS 353 and AGS 354 had significantly higher bottom pod heights in the 2013/14 season than in the 2012/13 season (Table 7.5.2). The bottom pod heights recorded for Lightning in both seasons were not significantly different. No significant differences in bottom pod height were measured as a result of the inoculants.

Bottom pod height was significantly positively correlated to yield, plant population and plant height, but significantly negatively correlated to 100-seed mass (Table 7.14). In the 2013/14 season bottom pod height was not significantly correlated to any agronomic characteristics (Table 7.16).

Over the two seasons, the bottom pod height of AGS 353 was significantly positively correlated to yield, plant height and percentage active nodules, but significantly negatively correlated to plant population, number of nodules plant^{-1} and nodule mass plant^{-1} (Table 7.15).

TABLE 7.5.1 ANOVA table of bottom pod height for the various cultivars and inoculant treatments for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	85.05	**	0.66	-
Cultivar	9.87	**	0.63	-
Inoculant	0.38	NS	0.63	-
Season x cultivar	17.72	**	0.92	-
Season x inoculant	1.11	NS	0.92	-
Cultivar x inoculant	0.75	NS	1.26	-
Season x cultivar x inoculant	1.46	NS	1.78	11.4

TABLE 7.5.2 Bottom pod height of the four cultivars in the two seasons

Season	AGS 352	AGS 353	AGS 354 (cm)	Lightning	Mean
2012/13	18.5 c	18.1 c	16.6 d	20.1 b	**18.3 y**
2013/14	21.7 a	20.4 b	20.4 b	19.6 b	**20.5 x**
Mean	**20.1 x**	**19.2 xy**	**18.5 y**	**19.8 xy**	**19.4**

7.4.1.5 Seed mass

No significant differences in 100-seed mass were measured among the seasons and inoculants and no significant interactions were measured between the seasons, cultivars and inoculants (Table 7.6.1). However, AGS 353 and AGS 354 had significantly higher mean 100-seed masses than AGS 352 and Lightning, between which a significant difference was measured (Table 7.6.2).

100-seed mass was significantly positively correlated to yield, but significantly negatively correlated to plant population, plant height and bottom pod height (Table 7.14).

Over the two seasons, the 100-seed mass of AGS 353 was significantly positively correlated to yield, plant height, and leaf N%, but significantly negatively correlated to plant population, nodule number plant^{-1} and nodule mass plant^{-1} (Table 7.15).

In the 2013/14 season 100-seed mass was significantly positively correlated to percentage active nodules, but significantly negatively correlated to plant population, plant height, number of nodules plant^{-1}, nodule mass plant^{-1} and leaf N% (Table 7.16).

TABLE 7.6.1 ANOVA table of 100-seed mass for the various cultivars and inoculant treatments for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	5.01	NS	1.87	-
Cultivar	1888.09	**	0.63	-
Inoculant	0.55	NS	0.63	-
Season x cultivar	1.09	NS	1.83	-
Season x inoculant	0.44	NS	1.83	-
Cultivar x inoculant	0.68	NS	1.26	-
Season x cultivar x inoculant	1.04	NS	2.26	6.1

TABLE 7.6.2 Mean 100-seed mass of the four cultivars

Cultivar	100-seed mass (g)
AGS 352	29.6 b
AGS 353	44.3 a
AGS 354	44.7 a
Lightning	25.8 c
Mean	**36.1**
F value	1888.01
P value	**
LSD (P<0.05)	0.63
CV %	6.1

7.4.1.6 Nodulation

Significant differences in the number of nodules plant^{-1} (Table 7.7.1) and the percentage active nodules (Table 7.7.2) of AGS 353 were measured between the seasons, but not between the inoculants. The number of nodules plant^{-1} was significantly higher in the 2012/13 season, whilst the percentage active nodules was significantly higher in the 2013/14 season (Table 7.7.3). No significant differences were measured for nodule mass plant^{-1} between the seasons and inoculants.

The number of nodules plant^{-1} and nodule mass plant^{-1} of AGS 353 were significantly positively correlated to plant population, but significantly negatively correlated to yield, plant height, bottom pod height, 100-seed mass, percentage active nodules and leaf N% (Table 7.15).

TABLE 7.7.1 ANOVA table of number of nodules plant^{-1} for AGS 353 and the inoculant treatments for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	15.81	*	17.62	-
Inoculant	1.63	NS	5.59	-
Season x inoculant	1.69	NS	17.25	21.1

TABLE 7.7.2 ANOVA table percentage active nodules for AGS 353 and the inoculant treatments for two trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	48.83	**	6.27	-
Inoculant	1.20	NS	5.35	-
Season x inoculant	2.69	NS	8.13	10.6

TABLE 7.7.3 Nodule number plant^{-1} and percentage active nodules for AGS 353 in the two seasons

Season	Nodules (no. plant^{-1})	Active nodules (%)
2012/13	58.5 a	79.9 b
2013/14	33.3 b	95.7 a
Mean	**45.9**	**87.8**

In the 2013/14 season, no significant differences were measured as a result of the inoculant treatments for number of nodules plant^{-1}, nodule mass plant^{-1} and percentage active nodules. Lightning had significantly larger and more nodules plant^{-1} than the other cultivars, among which no significant differences were measured (Table 7.8). However, Lightning had a significantly lower percentage of active nodules than the other cultivars. AGS 353 and AGS 354 had significantly higher percentages of active nodules than AGS 352.

In the 2013/14 season, the number of nodules plant^{-1} was significantly positively correlated to nodule mass plant^{-1} and plant height, but significantly negatively correlated to 100-seed mass (Table 7.16). Nodule mass plant^{-1} was significantly positively correlated to plant population and plant height, but significantly negatively correlated to yield, 100-seed mass and percentage active nodules. Percentage active nodules was significantly positively correlated to 100-seed mass, but significantly negatively correlated to plant population, plant height and nodule mass plant^{-1}.

TABLE 7.8 Nodule number, nodule mass and percentage active nodules for the four cultivars in the 2013/14 season

Cultivar	Nodules (no. plant^{-1})	Nodule mass (g plant^{-1})	100-nodule mass (g)	Active nodules (%)
AGS 352	31.1 b	0.89 b	2.86 b	88.7 b
AGS 353	33.3 b	0.87 b	2.72 b	95.7 a
AGS 354	29.5 b	0.81 b	2.70 b	95.5 a
Lightning	37.9 a	1.34 a	3.58 a	83.3 c
Mean	**32.9**	**0.98**	**2.97**	**90.8**
F value	5.32	23.73	18.41	40.44
P value	**	**	**	**
LSD (P<0.05)	4.44	0.14	0.27	2.63
CV %	33.3	35.7	22.7	7.2

7.4.1.7 Leaf nitrogen (N) content

The chlorophyll meter readings varied considerably due to variations in cloud cover and air temperature during recording. The measuring procedure was lengthy, due to the large number of readings. Consequently, no significant differences in the chlorophyll content of the leaves were measured among the four inoculant treatments. Leaf analysis for N% was therefore a more reliable measurement.

A significant interaction was measured for leaf N% between the cultivars and seasons (Table 7.9). The percentage leaf N of Lightning was significantly lower in the 2012/13 season than in the 2013/14 season. No significant differences in leaf N% were measured among the other cultivars and seasons. Mean leaf N% was significantly higher for AGS 352 and AGS 354 than for AGS 353 and Lightning.

No significant differences were measured for leaf N% as a result of the different inoculants.

Over the two seasons, leaf N% was significantly positively correlated to yield, plant height and 100-seed mass, but significantly negatively correlated to plant population, number of nodules plant^{-1} and nodule mass plant^{-1} (Table 7.15). In the 2013/14 season leaf N% was significantly positively correlated to yield and plant height, but significantly negatively correlated to 100-seed mass (Table 7.16).

TABLE 7.9 Leaf N% at early flowering of the four cultivars in the two seasons

	Cultivar				
Season	**AGS 352**	**AGS 353**	**AGS 354**	**Lightning**	**Mean**
		(%)			
2012/13	5.40 ab	5.38 ab	5.41 ab	5.10 b	**5.32**
2013/14	5.80 a	5.58 a	5.76 a	5.77 a	**5.73**
Mean	**5.60 x**	**5.48 y**	**5.59 x**	**5.44 y**	**5.53**
F value	11.18				
P value	**				
LSD (P0<0.05)	0.463				
CV %	5.1				

7.4.1.8 Yield

A significant interaction was measured for yield between the four cultivars and two seasons (Table 7.10.1). The yields obtained by all four cultivars in the 2013/14 season were significantly higher than those obtained in the 2012/13 season (Table 7.10.2). AGS 352 produced a significantly higher yield than Lightning in the 2012/13 season, but not in the 2013/14 season.

A significant interaction was measured for yield between the cultivars and inoculant treatments (Table 7.10.1). When comparing AGS 352, AGS 353 and AGS 354 individually, no significant differences in yield were measured as a result of the inoculant treatments (Table 7.10.3). However, when not inoculated, Lightning produced a significantly lower yield than when inoculated with the three inoculants and when compared with the other cultivars that were not inoculated. When inoculated with Soycap and Hi-stick, AGS 352 yielded significantly better than Lightning.

Yield was significantly positively correlated to plant height, bottom pod height, 100-seed mass, percentage active nodules and leaf N%, but significantly negatively correlated to plant population, number of nodules plant^{-1} and nodule mass plant^{-1} (Table 7.15).

TABLE 7.10.1 ANOVA table of seed yield for the various cultivars and inoculant treatments for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Season	27.60	**	264.0	-
Cultivar	11.63	**	72.5	-
Inoculant	2.83	*	72.5	-
Season x cultivar	4.31	**	257.5	-
Season x inoculant	1.53	NS	257.5	-
Cultivar x inoculant	2.07	*	145.0	-
Season x cultivar x inoculant	0.71	NS	291.5	7.6

TABLE 7.10.2 Seed yield of the four cultivars in the two seasons

	Cultivar				
Season	**AGS 352**	**AGS 353**	**AGS 354**	**Lightning**	**Mean**
		(kg ha^{-1})			
2012/13	3 296 b	3 069 bc	3 137 bc	2 964 c	**3 117 y**
2013/14	3 639 a	3 605 a	3 665 a	3 517 a	**3 616 x**
Mean	**3 468 x**	**3 337 y**	**3 401 xy**	**3 260 z**	**3 367**

TABLE 7.10.3 Seed yield of the four cultivars with the four inoculant treatments over two seasons

	Inoculant				
Cultivar	**Soycap**	**Eco-Rhizsoy®**	**Hi-stick®** (kg ha^{-1})	**Control**	**Mean**
AGS 352	3 500 ab	3 405 a-f	3 433 a-d	3 532 a	3 468 x
AGS 353	3 332 c-f	3 417 a-e	3 322 c-f	3 278 ef	3 337 y
AGS 354	3 437 a-d	3 452 a-c	3 336 c-f	3 379 c-f	3 401 xy
Lightning	3 379 c-f	3 302 d-f	3 267 f	3 092 g	3 260 z
Mean	**3 412 x**	**3 394 xy**	**3 339 yz**	**3 320 z**	**3 367**

The figure highlighted in red indicates a low yield.

7.4.1.9 Correlations

Correlation coefficients of the various agronomic characteristics were measured in the two trials at Cedara (Tables 7.14, 7.15 and 7.16).

Table 7.14 Correlation coefficients of various agronomic characteristics pooled from the two seasons at Cedara

	Yield (kg ha^{-1})	**Plant population ha^{-1}**	**Plant height (cm)**	**Bottom pod height (cm)**
Plant population ha^{-1}	-0.370 **	---	---	---
Plant height (cm)	0.247 **	0.064 NS	---	---
Bottom pod height (cm)	0.134 **	0.140 **	0.433 **	---
100-seed mass (g)	0.144 **	-0.204 **	-0.633 **	-0.140 **

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

TABLE 7.15 Correlation coefficients of various agronomic characteristics for AGS 353 pooled from the two seasons at Cedara.

	Yield (kg ha^{-1})	**Plant population ha^{-1}**	**Plant height (cm)**	**Bottom pod height (cm)**	**100-seed mass (g)**	**Nodules plant^{-1}**	**Nodule mass plant^{-1} (g)**	**Active nodules (%)**
Plant population ha^{-1}	-0.572 **	-	-	-	-	-	-	-
Plant height (cm)	0.584 **	-0.662 **	-	-	-	-	-	-
Bottom pod height (cm)	0.269 **	-0.350 **	0.404 **	-	-	-	-	-
100-seed mass (g)	0.338 **	-0.285 **	0.329 **	-0.010 NS	-	-	-	-
Nodules plant^{-1}	-0.490 **	0.631 **	-0.620 **	-0.342 **	-0.308 **	-	-	-
Nodule mass plant^{-1} (g)	-0.486 **	0.584 **	-0.480 **	-0.243 *	-0.457 **	0.824 **	-	-
Active nodules (%)	0.368 **	-0.634 **	0.487 **	0.264 **	0.040 NS	-0.430 **	-0.443 **	-
Leaf N (%)	0.364 **	-0.299 **	0.361 **	0.119 NS	0.247 *	-0.365 **	-0.499 **	0.126 NS

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

TABLE 7.16 Correlation coefficients of various agronomic characteristics pooled from the four cultivars in the 2013/14 season at Cedara

	Yield (kg ha^{-1})	Plant population ha^{-1}	Plant height (cm)	Bottom pod height (cm)	100-seed mass (g)	Nodules plant^{-1}	Nodule mass plant^{-1} (g)	Active nodules (%)
Plant population ha^{-1}	-0.090 NS	-	-	-	-	-	-	-
Plant height (cm)	-0.099 NS	0.546 **	-	-	-	-	-	-
Bottom pod height (cm)	-0.081 NS	0.122 NS	0.022 NS	-	-	-	-	-
100-seed mass (g)	0.137 NS	-0.457 **	-0.890 **	0.016 NS	-	-	-	-
Nodules plant^{-1}	-0.073 NS	-0.024 NS	0.142 *	-0.011 NS	-0.145 *	-	-	-
Nodule mass plant^{-1} (g)	-0.232 **	0.231 **	0.376 **	-0.007 NS	-0.367 **	0.691 **	-	-
Active nodules (%)	0.075 NS	-0.410 **	-0.631 **	-0.071 NS	0.578 **	-0.111 NS	-0.277 **	-
Leaf N (%)	0.235 **	0.072 NS	0.173 *	-0.043 NS	-0.154 *	-0.096 NS	-0.106 NS	-0.136 NS

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

7.4.2 DUNDEE EXPERIMENT

7.4.2.1 Climatic conditions

Although the total rainfall received over the growing period at Dundee was similar to the long-term mean, the distribution was extremely variable (Table 7.17). The soil was moist at planting and good rainfall was received within the month after planting. However, a very dry and hot spell with a mean maximum temperature of 28.8°C from 30/12/2013 to 17/01/2014 resulted in the death of many seedlings. From 06/02/2014 to 19/02/2014 another dry spell occurred with a mean maximum temperature of 28.7°C. From 12/03/2014 until the end of March only 11.5 mm of rainfall was received.

The mean monthly maximum temperatures were almost similar to the long-term mean in January and February, but slightly cooler during March and April (Table 7.18). The mean minimum temperatures were warmer from January to March than the long-term mean, but cooler during April.

TABLE 7.17 Rainfall received during the five month growing period in the 2013/14 season

Month	2013/2014 season	Long-term mean*
	(mm)	
December	223.5	131.0
January	42.4	135.1
February	95.8	108.9
March	123.4	82.4
April	3.3	42.7
Total	**488.4**	**500.1**

* 68 years" data (Source: ARC-ISCW).

The figures highlighted in red and green indicate the months when the rainfall was lower and higher than the long-term mean, respectively.

TABLE 7.18 Maximum and minimum temperatures measured during the five month growing period in the 2013/14 season at Dundee

	Maximum		Minimum	
	2013/14	Long-term mean*	2013/14	Long-term mean*
Month	(°C)		(°C)	
December	24.8	27.2	14.0	14.3
January	27.4	27.3	15.7	15.2
February	27.7	26.9	15.3	14.8
March	25.8	26.2	14.1	13.5
April	23.9	24.1	8.5	9.8

* 32 years" data (Source: ARC-ISCW).

7.4.2.2 Cultivars

Significant differences were measured among the four cultivars for nodulation and leaf N% (Table 7.19). No significant interactions were measured between nodule number plant^{-1}, nodule mass plant^{-1}, 100-nodule mass and percentage active nodules. AGS 352 had significantly more nodules plant^{-1} and a higher nodule mass plant^{-1} than AGS 354, but a significantly lower percentage of active nodules than the other three cultivars. However, the leaf N% of AGS 352 and Lightning was significantly higher than the leaf N% of AGS 353 and AGS 354. Lightning had a significantly higher 100-nodule mass than the other cultivars.

A significant positive correlation was measured between nodule number plant^{-1} and nodule mass plant^{-1} (Table 7.22). However, no significant correlations were measured between either nodule number plant^{-1} or nodule mass plant^{-1} for percentage pink nodules and leaf N (%). A significant positive correlation was measured between leaf N% and yield, but no significant correlation was measured between nodulation and yield.

TABLE 7.19 Nodules number, nodule mass, percentage pink nodules and percentage leaf nitrogen content at flowering for the four cultivars

Cultivar	Nodules (no. plant^{-1})	Nodule mass (g plant^{-1})	100-nodule mass (g)	Pink nodules (%)	Leaf N (%)
AGS 352	65.6 a	1.89 a	2.85 b	75.6 c	5.39 a
AGS 353	55.3 ab	1.65 ab	2.92 b	96.7 a	5.20 b
AGS 354	44.5 b	1.25 b	2.66 b	98.1 a	5.18 b
Lightning	56.0 ab	1.99 a	3.52 a	88.8 b	5.56 a
Mean	**55.4**	**1.69**	**2.99**	**89.8**	**5.33**
F value	3.39	4.08	4.94	21.9	7.95
P value	*	*	**	**	**
LSD ($P<0.05$)	13.59	0.47	0.48	6.36	0.18
CV %	29.4	33.5	19.4	8.5	4.1

The fungicide, captan, was applied as a seed coating to all the seed at planting. However, AGS 354 recorded a significantly lower plant population ha^{-1} than Lightning and AGS 352 (Table 7.20). The medium-season cultivars, AGS 353 and AGS 354, produced significantly shorter plants with significantly lower bottom pod heights, but higher 100-seed masses, than the long-season cultivars, AGS 353 and Lightning. AGS 354 produced a significantly lower yield than AGS 352 and Lightning.

Significant positive correlations were measured between plant population, plant height and bottom pod height (Table 7.22). No significant correlations were measured between plant population and either number of nodules plant^{-1}, nodule mass plant^{-1} or yield. However, as plant population increased, the percentage pink nodules decreased significantly, whilst leaf N% increased significantly. Significant negative correlations were measured between plant population and 100-seed mass and between yield and 100-seed mass.

TABLE 7.20 Plant population, plant height, bottom pod height, 100-seed mass and seed yield for the four cultivars

Cultivar	**Plant population (no. ha^{-1} x 1000)**	**Plant height**	**Bottom pod height**	**100-seed mass (g)**	**Seed yield (kg ha^{-1})**
		(cm)			
AGS 352	161.4 a	72.5 a	16.7 a	28.3 b	2 983 b
AGS 353	146.6 ab	61.1 b	12.5 b	43.3 a	2 890 bc
AGS 354	135.9 b	56.6 c	10.1 b	43.0 a	2 609 c
Lightning	162.5 a	73.8 a	15.7 a	26.5 b	3 307 a
Mean	**151.6**	**66.0**	**13.7**	**35.3**	**2 947**
F value	3.95	32.84	12.25	118.01	8.83
P value	*	**	**	**	**
LSD (P<0.05)	18.6	4.32	2.53	2.45	281.7
CV %	14.6	7.8	21.9	8.3	11.4

7.4.2.3 Inoculants

No significant differences were measured among the inoculant treatments for the number of nodules plant^{-1}, nodule mass plant^{-1}, 100-nodule mass, percentage pink nodules, leaf N% at flowering, plant population, plant height, 100-seed mass and seed yield (Table 7.21). However, a significantly higher bottom pod height was measured with Soycap than with Eco-Rhizsoy®.

TABLE 7.21 Plant population, plant height, bottom pod height, leaf nitrogen content, 100-seed mass and seed yield for the various inoculant treatments

Inoculant	Plant population (no. ha^{-1} x 1000)	Plant height	Bottom pod height (cm)	Leaf N (%)	100-seed mass (g)	Seed yield (kg ha^{-1})
Soycap	155.1	64.1	15.8 a	5.30	34.7	3 026
Eco-Rhizsoy®	150.9	65.4	11.9 b	5.38	35.4	3 041
Hi-Stick®	151.3	64.9	13.5 ab	5.31	34.6	2 977
Control	149.1	65.4	13.8 ab	5.34	36.4	2 745
Mean	**151.6**	**66.0**	**13.7**	**5.33**	**35.3**	**2 947**
F value	0.16	0.96	3.44	0.35	0.95	203
P value	NS	NS	*	NS	NS	NS
LSD (P<0.05)	18.6	4.32	2.53	0.18	2.45	281.7
CV %	14.6	7.8	21.9	4.1	8.3	11.4

7.4.2.4 Correlations

TABLE 7.22 Correlation coefficients of various agronomic characteristics pooled from the four cultivars at Dundee in the 2013/14 season

	Yield	**Plant population ha^{-1}**	**Plant height**	**Bottom pod height**	**100-seed mass**	**Nodules plant^{-1}**	**Nodule mass plant^{-1}**	**Active nodules (%)**
Plant population ha^{-1}	0.150 NS	-	-	-	-	-	-	-
Plant height	0.317 *	0.632 **	-	-	-	-	-	-
Bottom pod height	0.193 NS	0.525 **	0.760 **	-	-	-	-	-
100-seed mass	-0.402 **	-0.371 *	-0.626 **	-0.529 **	-	-	-	-
Nodules plant^{-1}	0.153 NS	0.157 NS	0.342 *	0.345 *	-0.114 NS	-	-	-
Nodule mass plant^{-1}	0.281 NS	-0.009 NS	0.338 *	0.354 *	-0.109 NS	0.630 **	-	-
Pink nodules (%)	-0.110 NS	-0.333 *	-0.564 **	-0.552 **	0.620 **	-0.126 NS	0.012 NS	-
Leaf N (%)	0.376 *	0.305 *	0.352 *	0.253 NS	-0.429 **	0.023 NS	-0.053 NS	-0.243 NS

Boxes highlighted in green and red are positively and negatively significant, respectively.
NS Not significant

TABLE 7.23 Soil analytical results from the sites used in the 2012/13 and 2013/14 season

Season	P	K	Ca	Mg	Exch. acidity	Total cations	Acid sat.	pH	Zn	Mn	Cu	Organic C	N	Clay
		(mg L^{-1})			(cmol L^{-1})		(%)	(KCl)		(mg L^{-1})			(%)	
2012/13	12	162	1092	203	0.22	7.75	3	4.52	4.0	6	4.7	3.1	0.23	43
2013/14	17	86	1052	155	0.31	7.06	4	4.45	4.4	5	5.6	2.6	0.18	44

TABLE 7.24 Soil analytical results from the site used in the 2013/14 season at Dundee

P	K	Ca	Mg	Exch. acidity	Total cations	Acid sat.	pH	Zn	Mn	Cu	Organic C	N	Clay
	(mg L^{-1})			(cmol L-1)		(%)	(KCl)		(mg L^{-1})			(%)	
39	282	449	94	0.11	3.85	3	4.82	2.3	9	1.1	1.0	0.06	18

7.5 DISCUSSION

The quantity of rainfall received in March in both seasons at Cedara affected the yields greatly, because pod-fill occurred during that month. The low rainfall recorded in March 2013 resulted in low yields, whilst the abundant rainfall received in March 2014 resulted in high yields, despite the high temperatures in February and March 2014. At Dundee above-average rainfall was received in March, which assisted in satisfactory yields being produced, because almost no rain was received in April. Soybean responds favourably to high soil moisture contents, particularly during the reproductive growth stages and especially during pod-fill (James, 2007; Comlekcioglu and Simsek, 2009; Demirtaş *et al*., 2013; Popovic *et al*., 2013; Adeboye *et al*., 2015). Long-season cultivars usually produce higher yields than shorter-season cultivars (Zhang and Kyei-Boahen, 2007; Swathi, 2009). This did not occur in either seasons at Cedara, but higher yields were produced by the long-season cultivars at Dundee, despite the lack of rain in April.

The total rainfall received at Cedara within seven days after planting was 25.7 mm and 51.8 mm in the 2012/13 and 2013/14 seasons, respectively. Some seed rot may have occurred due to the high quantity of rainfall received in the 2013/14 season, thus contributing to the significantly lower mean plant population ha^{-1} in the 2013/14 season (Table 7.3). However, the variations in plant population among the cultivars at both sites may have been due to seed quality and seed size. The low mean plant population at Dundee was due to the hot and dry conditions experienced in the first half of January, which destroyed many plants. In both trials at Cedara and in the trial at Dundee different cultivars recorded significantly low plant populations. However, the small-seeded cultivar, Lightning, had the highest mean plant populations at both site. Inconsistencies in plant populations with vegetable soybean cultivars over seasons have been reported by Duppong and Hatterman-Valenti (2005), Sanchez *et al*. (2005) and Hamilton (2007). Khalil *et al*. (2001) reported that small soybean seeds had better germination than large seeds, whilst Shelar *et al*. (2008) reported that seed storability was superior with small seeds than large seeds. Despite this, the small-seeded cultivar, AGS 352, had a low plant population in the 2012/13 season at Cedara. Shelar *et al*. (2008) stated that soybean seed deterioration rate and the ability to maintain seed longevity were genetically controlled, whilst cultivars with high oil contents usually had lower quality. Overall, plant population had no significant positive effect on yield (Tables 7.14, 7.15 and 7.21). Soybean plants compensate for variations in plant population and spacial distributions by adjusting their growth habits in order to maximize yield (Lee *et al*., 2008; Suhre, 2012). The inoculants had no effect on plant population. A similar result was measured by Solomon *et al*. (2012).

The plant height and bottom pod height of soybean cultivars are genetically determined, but are influenced by environmental factors. Lamptey *et al*. (2014) reported that plant height increased significantly with nodulation. However, the inoculants had no effect on plant height and bottom pod height. These plant characteristics increase with increasing plant population, due to competition for sunlight (Christmas, 2008; Epler and Staggenborg, 2008), and growing-season length (Hamilton, 2007; Zhang and Kyei-Boahen, 2007; Swathi, 2009). Hence, the long-season cultivars had taller plants with higher bottom pod heights at both sites. Plant height will be shorter with late planting dates, because of a shorter growing period resulting from warmer conditions (Liebenberg, 2012; Sadeghi and Niyaki, 2013). Despite a lower mean plant population in the 2013/14 season than in the 2012/13 season at Cedara, mean plant height and bottom pod height were significantly higher. The warmer temperatures and higher rainfall received during the vegetative growth stages may have boosted plant growth.

The differences in 100-seed mass among the various cultivars were similar to results obtained in other research trials conducted at Cedara (Tables 7.6 and 7.19). Seed mass is genetically determined, but is affected by the growing conditions. Significant negative correlations were measured between 100-seed mass and plant population (Tables 7.14, 7.15 and 7.21), due to the long-season cultivars generally having higher plant stands and lower 100-seed masses. However, James (2007) reported that 100-seed mass decreased linearly as seeding rate increased from 50 000 to 400 000 seeds ha^{-1}, but there was little change in seed mass at seeding rates below 200 000 seeds ha^{-1}. The inoculants had no effect on 100-seed mass. Significant positive correlations were measured between 100-seed mass and yield at Cedara, due to the larger seeded cultivars, AGS 353 and AGS 354, producing higher yields, whilst at Dundee a significant negative correlation was measured for the opposite reason (Table 7.21). Epler and Staggenborg (2008) reported that seed mass influenced grain yield significantly.

The significantly lower number of nodules $plant^{-1}$ recorded in the 2013/14 season at Cedara may have resulted from the hotter and drier conditions (Hungria and Vargas, 2000) experienced in January and February (Tables 7.1 and 7.2) or a lower soil *Rhizobium* population before planting than the 2012/13 site. Under favourable conditions, nodulating bacteria can remain in the soil for several years (Liebenberg, 2012). The number of nodules $plant^{-1}$ for the control treatment was not significantly lower than the number of nodules $plant^{-1}$ for the three inoculants. Agrochemicals have been reported to reduce nodulation (Campo *et al*., 2010). However, the agrochemicals used were the same in both seasons. High levels of soil N will discourage soybean plants from nodulating (Campo *et al*., 2010; Emam and Rady, 2014). However, the N levels were lower in the 2013/14 season than in the 2012/13 season (Table 7.22). Low soil phosphorus (P) and potassium (K) levels can prevent nodulation (Kumaga *et al*, 2004; Waluyo *et al*., 2004; Imas *et al*., 2007; Zarrin *et al*., 2007; Bekere and Hailemariam, 2012). However, sufficient levels of P and K were present at planting. Soil pH (KCl) levels below 5.2 can prevent nodulation (Liebenberg, 2012). The pH (KCl) levels were 4.52 and 4.45 in the 2012/13 and 2013/14 seasons, respectively (Table 7.22).

Salvucci *et al*. (2012) and Solomon *et al.* (2012) reported variations in the number of nodules plant^{-1} among cultivars. At both sites, Lightning had more nodules plant^{-1} and the highest nodule mass plant^{-1}, indicating greater nodule prolificacy than the other cultivars. AGS 354 recorded the lowest number of nodules plant^{-1} at both sites. The earlier maturing cultivars, AGS 353 and AGS 354, recorded significantly higher percentages of active nodules at both sites than the later maturing cultivars, AGS 352 and Lightning. Salvucci *et al.* (2012), however, found that growing-season length had no effect on nodulation ability.

Although significantly fewer nodules plant^{-1} were measured at Cedara in the 2013/14 season than in the 2012/13 season, the higher percentages of active nodules and leaf N, together with the good rainfall during pod-fill resulted in a significantly higher mean yield. At Dundee, despite a high number of nodules plant^{-1} and a high percentage of active nodules, the yields were lower due to less rainfall during pod-fill than at Cedara. Therefore, rainfall had a greater effect on yield than nodulation.

Although variations in nodulation were measured among the cultivars, mean leaf N% was significantly higher at Cedara for AGS 352 and AGS 354, whilst at Dundee, AGS 352 and Lightning recorded significantly higher leaf N%. A significant positive correlation was measured between leaf N% and yield in all the experiments, indicating that leaf N% was a better indicator of yield than the number of nodules plant^{-1}, nodule mass plant^{-1} and percentage active nodules. However, Lamptey *et al*. (2014) measured a significant positive correlation between grain yield and the number and weight of nodules.

At Cedara, Lightning produced a significantly lower yield when not inoculated (Table 7.13), indicating that inoculation is necessary for this cultivar, even when inoculated soybean had been grown on the land in previous seasons. This result was not observed in the trial at Dundee. However, soybean had previously been grown on the Dundee site four years prior to the experiment, whilst at Cedara no soybean had been grown on the sites within the previous ten years. The significantly low yield produced by AGS 354 at Dundee was probably due to a combination of low plant population, low plant height, low number of nodules plant^{-1}, low nodule mass plant^{-1} and low leaf N%.

At Cedara, the application of Soycap and Eco-Rhizsoy® resulted in significantly higher mean yields than the Control treatment (Table 7.12). Although the highest yields were produced when the seeds were inoculated with Soycap and Eco-Rhizsoy® at Dundee, no significant differences in yield were measured as a result of the different inoculants. Zarrin *et al*. (2007) and Solomon *et al.* (2012) reported significant differences as a result of the inoculants for seed mass plant^{-1}. Lamptey *et al*. (2014) reported that *Rhizobium* inoculation significantly increased soybean grain yield in lands not previously planted to soybean. Jordan (2010) reported that inoculation did not increase yield in lands previously planted to soybean. However, Conley and Christmas (2006) reported increases up to 5%. The response to inoculation may therefore depend on several factors including the existing *B. japonicum* population, soil N availability and plant uptake of soil N (Jordan, 2010). As the inoculant is relatively cheap, inoculation is recommended, even when soybean had been grown on the land in previous seasons.

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CHAPTER 8

FINANCIAL ANALYSIS OF VEGETABLE SOYBEAN PRODUCTION IN KWAZULU-NATAL

8.1 ABSTRACT

Vegetable soybean (*Glycine max* (L.) Merrill) is poorly known in South Africa and there is no known commercial production of the crop. However, research trials conducted at the Cedara Research Station (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), KwaZulu-Natal, South Africa, have shown that the crop is well-adapted to the environmental conditions experienced in the KwaZulu-Natal Midlands. A financial analysis was undertaken to determine the costs and profitability of vegetable soybean when produced under irrigated and dryland conditions and marketed as (a) fresh ungraded green pods in 10 kg vegetable pockets, (b) marketable fresh green pods (≥ 2 beans pod^{-1}) sold in 10 kg vegetable pockets plus the 1-seeded pods being shelled and the fresh green beans sold in plastic punnets; and (c) the whole crop sold as shelled fresh green beans in plastic punnets. It was considered that land preparation, planting and spraying operations are done mechanically, whilst labour is used for hand-harvesting, grading, shelling and packing at R120.32 per nine hour day. Fresh green pod yields of 7 and 10 t ha^{-1} are used for dryland and irrigation, respectively. Five percent of the crop is rejected due to damage and malformation. The percentages of marketable green pods are 70% and 80% for dryland and irrigation, respectively. A price of R7.00 kg^{-1} for marketable pods is used, but adjusted according to the percentage marketable pods when all the green pods are sold. The fresh green beans are sold at R20.00 kg^{-1}. Marketing agents are used to sell the crop, which is delivered to the market by a transport contractor. The higher yields produced with irrigation result in greater gross margins ha^{-1} above total allocatable variable costs (TAVC) and returns on investment (ROI) than the yields produced under dryland conditions. The lowest gross margins ha^{-1} above TAVC of R17 117.12 and R32 337.98 are obtained with dryland and irrigation, respectively, when the ungraded green pods are sold in 10 kg vegetable pockets. The highest gross margins ha^{-1} above TAVC of R36 921.67 and R54 544.23 are obtained with dryland and irrigation, respectively, when the whole crop is marketed as green beans in plastic punnets. With the cost and prices used, edamame production can be economically viable in KwaZulu-Natal.

Keywords: Edamame, allocatable variable costs, gross margins, green pods, green beans

8.2 INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merrill) is the same species as grain soybean, but cultivars have been bred specifically for harvesting at an immature stage for direct consumption by humans (Rao *et a*l., 2002). Edamame is harvested when the pods are still bright green and the beans have filled 80% to 90% of the pod and are almost touching each other. This occurs at the reproductive growth stage R6, when the sugars and amino acids required for good taste are at their peak (Duppong and Hatterman-Valenti, 2005; Hamilton, 2007; Zhang *et al.*, 2007) and the moisture content of the beans is around 70% (Feibert *et al.*, 2001).

The shelled fresh green beans are regularly eaten in China, Korea, Taiwan and Japan, where it is known as edamame. Due to its recognition as a highly nutritional and health-benefitting crop and due to its tastiness (Duppong and Hatterman-Valenti, 2005; Sciarappa *et al*., 2007), edamame is now grown in many other parts of the world (Sharma, 2013).

There is no known commercial production of edamame in South Africa. Therefore determination of the profitability of edamame in South Africa is based on estimations. The financial success of a crop will be governed by the forces of supply and demand. As the majority of the people in South Africa are unaware of edamame, an awareness campaign highlighting the health benefits and uses of this high protein crop will be required to create a demand. Large chain stores will need to be guaranteed a continuous supply of edamame for at least nine months of the year. This is possible if the crop is frozen. The cultivars available are not genetically modified and therefore the crop can also be grown organically.

Edamame, being a speciality crop, requires good management to produce a high-quality, directly consumed product. The key determinants of quality are large seed size (seed dry weight > 25 g 100-seeds^{-1}, but for the export market ≥ 30 g 100-seeds^{-1}), high sugar content, bright green colour with good flavour, texture and nutritional value. The pods should be dark green, have a light (white, grey or light brown) pubescence, contain at least two beans and be free of defects (Nelson *et al*., 2002; Born, 2006; James, 2007). The pods should be ≥ 5.0 cm in length and ≥ 1.4 cm in width (Mentreddy *et al*., 2002; Born, 2006).

Grain soybean is successfully grown in KwaZulu-Natal under dryland conditions in the higher rainfall areas and under irrigation in the drier areas and/or where erratic rainfall is expected. Based on budgets developed by the Agricultural Economics Section of the KwaZulu-Natal Department of Agriculture and Rural Development, in the production year 2014/15, a 2 t ha^{-1}

grain soybean crop was produced under dryland conditions at a total allocatable variable cost of R6800.00 ha^{-1} and sold at a price of R5 000.00 ton^{-1}, had a gross margin above total allocatable variable costs of R3 200.00 ha^{-1}. A 3.5 t ha^{-1} grain soybean crop was produced under irrigation at a total allocatable variable cost of R9 100.00 ha^{-1} and sold at a price of R5 000.00 ton^{-1}, had a gross margin above total allocatable variable costs of R8 400.00 ha^{-1}. When soybean is grown under no-till conditions, lower fuel, repairs and maintenance costs will be incurred, which will increase the profitability.

Apart from seed costs, which may be higher for edamame than for grain soybean, the costs incurred in growing the crop will be similar to grain soybean. However, labour costs will be considerably higher with edamame when harvested manually (Zhang and Kyei-Boahen (2007). Machine harvesting with a green bean (*Phaseolus vulgaris* L.) harvester will definitely be more economical (Born, 2006). However, harvest efficiency can vary from 54% to 85% depending on plant spacing and height (Zandonadi *et al*., 2009). Therefore, the market price of edamame will have to be high enough to ensure profitability. In a budget compiled by Ernst (2001), projected net returns of \$400 - \$2500 $acre^{-1}$ could be achieved. These returns translate to R5 516 – R34 375 ha^{-1} at the exchange rate of R13.79/\$. Therefore, the returns per hectare could easily be more than twice that of grain soybean.

In an economic viability study conducted by Shockley *et al*. (2011), a market price of R11.40 kg^{-1} for organically grown edamame was required at the time of the study for farmers to switch from grain soybean to edamame. The authors calculated that greater maximum net returns could be achieved with edamame than with grain soybean, but cautioned that there could be greater risk involved with edamame production, and greater farming skills with very tight harvesting windows.

The manner in which the crop is marketed also influences profitability. The crop can be sold either as whole plants, green pods or green beans. The Japanese consider the marketing of whole plants as the most desirable, because the pod quality is preserved and therefore higher prices can be obtained (Born, 2006). Harvesting costs would be reduced, because less labour would be required to remove the pods from the plants. However, when bundled and packed into wooden boxes or cartons, an additional packaging cost would be incurred. Small-scale farmers in KwaZulu-Natal may prefer to market edamame in bunches as this would be the easiest and cheapest method. When sold as shelled green beans machinery and additional labour costs would be incurred.

8.3 MATERIALS AND METHODS

Three scenarios are presented:

i) All the fresh ungraded green pods are marketed in 10 kg green vegetable pockets.
ii) All the marketable pods (≥ 2 beans pod^{-1}) are sold in 10 kg green vegetable pockets and the 1-seeded pods are shelled and the green beans sold in 250 g plastic punnets.
iii) All the pods are shelled and the green beans sold in 250 g plastic punnets.

For this exercise the following assumptions are made:

a) Land preparation is done conventionally (see Tables 1 and 2).

b) The seed is planted with a tractor-drawn 4-row mounted planter.

c) Herbicides, pesticides and fungicides are applied with a tractor-mounted spray-boom.

d) The agronomic characteristics and yields are based on results obtained in the research trials conducted on vegetable soybean grown under dryland conditions at the Cedara Research Station, KwaZulu-Natal, South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m), where the mean annual rainfall is 880 mm, of which about 745 mm falls from October to April. The annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999).

e) The crop is harvested at the R6 stage when the pods are still bright green and the beans have filled 80% to 90% of the pod.

f) On-farm management is 70% efficient compared to research trials due to the size of the operation. Therefore, a green pod yield of 10 t ha^{-1} is produced under irrigation and 7 t ha^{-1} is produced under dryland (rain-fed) conditions. The mean yield of twenty cultivars evaluated under dryland conditions at Cedara over three seasons was 9.7 t ha^{-1}.

g) It is assumed that 70 % and 80% of the pods contain ≥ 2 beans pod^{-1} under dryland conditions and with irrigation, respectively.

h) Due to possible insect and harvest damages and deformities, 5% of the crop is rejected.

i) Green pod yield is 50% of the whole above-ground plant, whilst green bean yield is 50% of the green pod yield.

j) Due to the assumption that 70% and 80% of the pods contain ≥ 2 beans pod^{-1} when grown under dryland conditions and with irrigation, respectively, the return from selling all the pods sold in 10 kg green pockets is R6.00 and R6.80 kg^{-1}, respectively (Tables 3 and 4). When selling only the marketable pods (≥ 2 beans pod^{-1}) in 10 kg green vegetable pockets the price is R7.00 kg^{-1}. The remaining 1-seeded pods are shelled and the beans sold at R20.00 kg^{-1} in plastic punnets containing 250 g of beans each (Tables 5 and 6). In Tables 7 and 8 only the shelled green beans are marketed and sold in plastic punnets at R20.00 kg^{-1}.

k) A price of R35.00 kg^{-1} for seed is used.

l) Seeding rates of 75 000 and 100 000 seeds ha^{-1} are used for dryland and irrigation, respectively.

m) Fertilizer applications will differ according to analyses of soil samples. As a general estimate, 20 kg P ha^{-1} and 40 kg K ha^{-1} are used.

n) A fungicide, thiram, and a *Bradyrhizobium japonicum* Kirchner inoculant are applied as seed coatings at planting.

o) Two pre-emergence herbicides, S-metolachlor (Dual S Gold® EC, 915 g a.i. L^{-1}, Syngenta[1]) and imazethapyr (Hammer® SL, 100 g a.i. L^{-1}, BASF[2]), are applied with a tractor-mounted spray-boom at the recommended rates for clay percentages above 40%. One post-emergence herbicide, bendioxide (Basagran® SL, 480 g a.i. L^{-1}, BASF) is applied.

[1] Syngenta South Africa (Pty), Ltd., Private Bag X60, Halfway House, 1685. Tel.: 011 541 4000.

[2] BASF, P.O. Box 444, Umbogintwini, 4120. Tel.: 031 9047860.

p) Three applications of an cypermethrin-based insecticide are used: one application at planting applied with the pre-emergence herbicides to control cutworm (*Agrotis segetum* Denis and Schifferműller), one applied just before flowering and one during pod-fill to control insects, especially African bollworm (*Helicoverpa armigera* Hűbner).

q) The systemic fungicide, carbendazim/flusilazole (Punch Xtra®, 250/125 g a.i. L^{-1}, Du Pont de Nemours[1]) is applied with a tractor-mounted spray-boom at a rate of 0.4 L ha^{-1} just before flowering together with the insecticide, and is repeated three weeks later to control Asian soybean rust (*Phakopsora pachyrhizi* Sydow).

r) Casual labour at a cost of R120.32 day^{-1} is required to hand-harvest the crop in the field, load the plants onto a trailer, unload the plants at the packing shed, remove the pods from the plants, grade the pods for marketable (≥ 2 beans pod^{-1}), 1-seeded and rejects, bag the marketable pods or shell the pods and place the beans in punnets as required. The number of labour days required varies according to yield. Therefore more labour days are required when the crop is grown under irrigation (100 labour days) compared to under dryland conditions (70 labour days). The quantity of labour required for harvesting is based on the labour required for green bean (*Phaseolus vulgaris* L.) production.

s) A shelling machine with rollers is used for shelling the pods.

t) Crop insurance is based on yields of 3.5 t ha^{-1} and 2.0 t ha^{-1} under irrigation and dryland conditions, respectively, for mature grain soybean with a value of R5 358.25 ton^{-1}.

u) The crop is marketed through an agent at the market and therefore a commission is paid.

v) A contractor is used to transport the product to the market.

[1]Du Pont de Nemours, 1st Floor Block B, 34 Whiteley Road, Melrose Arch, 2196. Tel.: 011 218 8600.

w) Table 8.1 indicates the tractors and implements required and their repairs and maintenance costs for the operations required to plant and manage the crop in a conventionally tilled land (Archer and Lubbe, 2015). The fuel usage per hour for the two tractor types under low, medium and high power requirements is also included in Table 1. The price of the fuel at the time of conducting the calculations was R12.95 per litre.

x) The operation costs per hectare are based on the number of hectares an operator can treat in an eight hour day, the cost per hour and the fuel price (Table 8.2) (Archer and Lubbe, 2015). These are presented as indirectly allocatable variable pre-harvest costs.

y) The cost of a tractor driver and, where necessary, an assistant at R13.39 per hour is dependent upon the operation time multiplied by 1.5 (Table 8.2). This cost is included in the indirectly allocatable variable pre-harvest costs.

z) Return on investment (ROI) is calculated as:
ROI = (Gain from investment – cost of investment)/Cost of investment x 100.

TABLE 8.1 Repairs and maintenance costs for the tractors and implements, fuel usage by the tractors under low, medium and high power requirements and fuel price per litre

Tractor and implement description	Repairs and maintenance costs (R/hr)	Fuel usage (L/hr)			Fuel price (R/L)
		Low	Medium	High	
46 kW 2 wheel drive tractor	26.50	6.44	7.25	8.28	12.95
60 kW 2 wheel drive tractor	44.58	8.40	9.45	10.80	
3.05 m trailed offset disc harrow	54.58				
3 furrow reversible mouldboard plough	38.76				
3.05 trailed offset disc harrow	54.58				
3.0 m (31 tine) S-shank tiller with roller	12.26				
4 row (0.75/0/9 m) Mech/Mech mounted maize planter	55.13				
6 m – 10 m (400 L) mounted boom sprayer	9.99				
3 ton trailer with brakes for tractor (fertilizer for planting; 1 trip)	3.91				
3 ton trailer with brakes for tractors (dryland beans 14 tons/ha; 5 trips)	3.91				
3 ton trailer with brakes for tractors (irrigated beans 20 tons/ha; 7 trips)	3.91				

TABLE 8.2 Tractor and implement costs and labour costs per hectare according to the operation and type of equipment used

				Tractor + implement			Labour		
Operation	**Equipment**	**Ha/day**	**Hrs/day**	**Hrs/ha**	**R/hr**	**R/ha**	**Hrs/ha**	**R/hour**	**R/ha**
Disc	60 kW tractor + 3.05 m trailed offset disc harrow (H)*	20.00	8.00	0.40	239.02	95.61	0.60[1]	13.39	8.03
Plough	60 kW tractor + reversible mouldboard plough (H)	3.50	8.00	2.29	223.20	510.17	3.43[1]	13.39	45.91
Disc	60 kW tractor + 3.05 m trailed offset disc harrow (H)	20.00	8.00	0.40	221.54	88.62	0.60[1]	13.39	8.03
Cultivate	46 kW tractor + tiller with roller (L)^	20.00	8.00	0.40	122.16	48.86	0.60[1]	13.39	8.03
Plant	46 kW tractor + 4 row (0.75/0.9 m) mech. mounted planter	13.00	8.00	0.62	165.03	101.56	1.85[2]	13.39	24.72
Spray x 4 applications	46 kW tractor + mounted 6 m – 10 m boom sprayer, 400 L tank	22.00	8.00	0.36	479.56	174.39	1.09[2]	13.39	14.61
Transport fertilizer to the field at planting.	46 kW tractor + 3 ton trailer with brakes (L)		8.00	0.20	113.81	22.76	0.60[2]	13.39	8.03
Transport dryland bean plants from field; 14 tons; 5 trips	46 kW tractor + 3 ton trailer with brakes (L)		8.00	1.00	113.81	113.81	3.00[2]	13.39	40.17
Transport irrigated bean plants from field; 20 tons; 7 trips	46 kW tractor + 3 ton trailer with brakes (L)		8.00	1.40	113.81	159.34	4.20[2]	13.39	56.24
	TOTAL					**1315.12**			**213.78**

*H = High fuel usage; ^L = Low fuel usage.

[1]Tractor driver‟s time = machine time * 1.5

[2]Tractor driver‟s time + 1 assistant‟s time = machine time * 3

8.4 RESULTS

8.4.1 Crop marketed as ungraded green pods

After deducting 5% of the 7 ton ha^{-1} yield produced under dryland conditions as rejects, 6.65 tons of fresh ungraded green pods sold at R6 000.00 ton^{-1} results in a gross income of R39 900.00 ha^{-1} (Table 8.3). The pre-harvest costs were R5 433.31 for directly allocatable variable costs (DAVC) and R1 313.32 for indirectly allocatable variable costs (IAVC), whilst the harvest and marketing costs, which included labour, packaging, marketing commissions and transport to the market, accounts for R16 036.25. The gross margin above total allocatable variable costs (TAVC) is R17 117.12 ha^{-1}.

After deducting 5% of the 10 ton ha^{-1} yield produced under irrigation as rejects, 9.5 tons sold at R6 800.00 ton^{-1} results in a gross income of R64 600.00 ha^{-1} (Table 8.4). The pre-harvest costs are R7 027.60 for DAVC and R1 374.92 for IAVC, whilst the harvest costs are R23 859.50. The gross margin above TAVC is R32 337.98 ha^{-1}.

TABLE 8.3 Gross margin for dryland (rain-fed) vegetable soybean sold as green pods

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Ungraded green pods	Ton	6 000	6.65	39 900.00
TOTAL (A)				**39 900.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.03	1 050.00
Soybean inoculant (400 g packet)	Each	145.91	0.75	109.43
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin® (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra®	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	0	0	0
Crop Insurance: Soybean 10.0%	Ton	535.83	2.5	1 339.58
TOTAL (B)				**5 433.31**
HARVEST COSTS (C)				
Packaging: 10 kg green vegetable pockets	Each	1.20	665	798.00
Casual labour	Days	120.32	70	8 422.00
Marketing cost				
Agents commission	7.50%			2 992.50
Market commission	5.00%			1 995.00
Transport: Contract	Ton	275.00	6.65	1 828.75
TOTAL (C)				**16 036.25**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 313.32
TOTAL (D)				**1 313.32**
TOTAL PRE-HARVEST COSTS (B+D)				**6 746.63**
TOTAL HARVEST COSTS (C)				**16 036.25**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**21 469.56**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 313.32**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**22 782.88**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VAR. COSTS (A - F)				**17 117.12**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**18 430.44**

TABLE 8.4 Gross margin for irrigated vegetable soybean sold as whole green pods

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Ungraded green pods	Ton	6 800	9.50	64 600.00
TOTAL (A)				**64 600.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.04	1 400.00
Soybean inoculant (400 g packet)	Each	145.91	1.0	145.91
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin® (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra® (2 applications)	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	3.36	200.00	672.00
Crop Insurance: Soybean 10.0%	Ton	5 358.25	3.50	1 875.39
TOTAL (B)				**7 027.60**
HARVEST COSTS (C)				
Packaging: 10 kg green vegetable pockets	Each	1.20	950	1 140.00
Casual labour	Days	120.32	100	12 032.00
Marketing cost				
Agents commission	7.50%			4 845.00
Market commission	5.00%			3 230.00
Transport: Contract	Ton	275.00	9.5	2 612.50
TOTAL (C)				**23 859.50**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 374.92
TOTAL (D)				**1 374.92**
TOTAL PRE-HARVEST COSTS (B+D)				**8 402.52**
TOTAL HARVEST COSTS (C)				**23 859.50**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**30 887.10**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 374.92**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**32 262.02**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VARIABLE COSTS (A - F)				**32 337.98**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**33 712.90**

8.4.2 Crop marketed as green pods and shelled green beans

After deducting 5% of the 7 ton ha^{-1} yield produced under dryland conditions as rejects, 4.65 tons of marketable pods (≥ 2 beans pod^{-1}) are sold at R7 000.00 ton^{-1} and the shelled 1-seeded pods are sold in punnets at R20.00 kg^{-1}. The gross income is R52 550.00 ha^{-1} (Table 8.5). The pre-harvest costs are R5 433.31 for DAVC and R1 313.32 for IAVC, whilst the harvest costs account for R18 542.90. The gross margin above TAVC is R27 260.67 ha^{-1}.

After deducting 5% of the 10 ton ha^{-1} yield produced under irrigation as rejects, 7.60 tons of marketable pods is sold at R7 000.00 ton^{-1} and the 1-seeded pods are shelled and sold in plastic punnets as green beans at R20.00 kg^{-1}. This results in a gross income of R72 200.00 ha^{-1} (Table 8.6). The pre-harvest costs are R7 027.60 for DAVC and R1 374.92 for IAVC, whilst the harvest costs account for R25 949.50. The gross margin above TAVC is R37 847.98 ha^{-1}.

TABLE 8.5 Gross margin for dryland vegetable soybean sold as green pods and beans

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Marketable green pods (≥ 2 beans pod^{-1})	Ton	7 000	4.65	32 550.00
Shelled green beans	Ton	20 000	1.00	20 000.00
TOTAL (A)				**52 550.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.03	1 050.00
Soybean inoculant (400 g packet)	Each	145.91	0.75	109.43
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin® (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra®	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	0	0	0
Crop Insurance: Soybean 10.0%	Ton	535.83	2.5	1 339.58
TOTAL (B)				**5 433.31**
HARVEST COSTS (C)				
Packaging: 10 kg green vegetable pockets	Each	1.20	465	558.00
Punnets: 250 g per punnet	Each	0.36	4000	1 440.00
Casual labour	Days	120.32	70	8 422.00
Marketing cost				
Agents commission	7.50%			3 941.25
Market commission	5.00%			2 627.50
Transport: Contract	Ton	275.00	5.65	1 553.75
TOTAL (C)				**18 542.90**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 313.12
TOTAL (D)				**1 313.12**
TOTAL PRE-HARVEST COSTS (B+D)				**6 746.43**
TOTAL HARVEST COSTS (C)				**18 542.90**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**23 976.21**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 313.12**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**25 289.33**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VAR. COSTS (A - F)				**27 260.67**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**28 573.79**

TABLE 8.6 Gross margin for irrigated vegetable soybean sold as green pods and beans

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Marketable green pods (≥ 2 beans pod^{-1})	Ton	7 000	7.60	53 200.00
Shelled green beans	Ton	20 000	0.95	19 000.00
TOTAL (A)				**72 200.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.04	1 400.00
Soybean inoculant (400 g packet)	Each	145.91	1.0	145.91
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin® (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra® (2 applications)	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	3.36	200.00	672.00
Crop Insurance: Soybean 10.0%	Ton	5 358.25	3.50	1 875.39
TOTAL (B)				**7 027.60**
HARVEST COSTS (C)				
Packaging: 10 kg green vegetable pockets	Each	1.20	760	912.00
Punnets: 250 g per punnet	Each	0.36	3 800	1 368.00
Casual labour	Days	120.32	100	12 032.00
Marketing cost				
Agents commission	7.50%			5 415.00
Market commission	5.00%			3 610.00
Transport: Contract	Ton	275.00	8.55	2 351.25
TOTAL (C)				**25 688.25**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 374.92
TOTAL (D)				**1 374.92**
TOTAL PRE-HARVEST COSTS (B+D)				**8 402.52**
TOTAL HARVEST COSTS (C)				**25 688.25**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**32 715.85**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 374.92**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**34 090.77**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VARIABLE COSTS (A - F)				**38 109.23**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**39 484.15**

8.4.3 Crop market as shelled green beans

After deducting 5% of the 7 ton ha^{-1} yield produced under dryland conditions as rejects, 3.3 tons of green beans are sold at R20.00 kg^{-1} resulting in a gross income of R66 000.00 ha^{-1} (Table 8.7). The pre-harvest costs are R5 433.31 for DAVC and R1 313.32 for IAVC, whilst the harvest costs are R22 331.90. The gross margin above TAVC is R36 921.67 ha^{-1}.

After deducting 5% of the 10 ton ha^{-1} yield produced under irrigation as rejects, 4.75 tons of green beans are sold at R20.00 kg^{-1} in 250 g punnets resulting in a gross income of R95 000.00 ha^{-1} (Table 8.8). The pre-harvest costs are R7 027.60 for DAVC and R1 374.92 for IAVC, whilst the harvest costs are R32 053.25. The gross margin above TAVC is R54 544.23 ha^{-1}.

TABLE 8.7 Gross margin for dryland vegetable soybean sold as shelled green beans

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Shelled green beans	Ton	20 000	3.3	66 000.00
TOTAL (A)				**66 000.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.03	1 050.00
Soybean inoculant (400 g packet)	Each	145.91	0.75	109.43
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra®	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	0	0	0
Crop Insurance: Soybean 10.0%	Ton	535.83	2.50	1 339.58
TOTAL (B)				**5 433.31**
HARVEST COSTS (C)				
Packaging:				
Punnets: 250 g per punnet	Each	0.36	13 200	4 752.00
Casual labour	Days	120.32	70	8 422.40
Marketing cost				
Agents commission	7.50%			4 950.00
Market commission	5.00%			3 300.00
Transport: Contract	Ton	275.00	3.3	907.50
TOTAL (C)				**22 331.90**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 313.12
TOTAL (D)				**1 313.12**
TOTAL PRE-HARVEST COSTS (B+D)				**6 746.43**
TOTAL HARVEST COSTS (C)				**22 331.90**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**27 765.21**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 313.12**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**29 078.33**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VAR. COSTS (A - F)				**36 921.67**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**38 234.79**

TABLE 8.8 Gross margins for irrigated vegetable soybean sold as shelled green beans

	Unit	Price per unit (R)	Quantity	R ha^{-1}
GROSS INCOME				
Product Income				
Shelled green beans	Ton	20 000	4.75	95 000.00
TOTAL (A)				**95 000.00**
DIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COSTS (B)				
Plant material				
Vegetable soybean seed	Ton	35 000.00	0.04	1 400.00
Soybean inoculant (400 g packet)	Each	145.91	1.0	145.91
Fertilizer				
Single superphosphate (10.5% P)	Ton	5 416.40	0.20	1 083.28
Potassium chloride (50% K)	Ton	6 213.90	0.08	497.11
Trace elements				
Molyflo	Litre	25.18	0.3	7.55
Herbicides				
Dual S Gold ®	Litre	167.39	1.30	217.61
Hammmer®	Litre	373.01	0.50	186.51
Basagran®	Litre	184.95	3.0	554.85
Insecticides				
Kemprin® (3 applications)	Litre	102.99	0.6	61.79
Fungicides				
Thiram	Kg	71.64	0.06	4.30
Punch Xtra®	Litre	362.83	0.8	290.26
Wetting agent				
Summit Super	Litre	51.73	0.60	31.04
Irrigation	mm	3.36	200.00	672.00
Crop Insurance: Soybean 10.0%	Ton	535.83	3.50	1 875.39
TOTAL (B)				**7 027.60**
HARVEST COSTS (C)				
Packaging:				
Punnets: 250 g per punnet	Each	0.36	6000	6 840.00
Casual labour	Days	120.32	100	12 032.00
Marketing cost				
Agents commission	7.50%			7 125.00
Market commission	5.00%			4 750.00
Transport: Contract	Ton	275.00	4.75	1 306.25
TOTAL (C)				**32 053.25**
INDIRECTLY ALLOCATABLE VARIABLE COSTS				
PRE-HARVEST COST (D)				
Machinery repairs and maintenance costs, fuel, tractor driver and assistant costs	Ha			1 374.92
TOTAL (D)				**1 374.92**
TOTAL PRE-HARVEST COSTS (B+D)				**8 402.52**
TOTAL HARVEST COSTS (C)				**32 053.25**
TOTAL DIRECTLY ALLOCATABLE VARIABLE COSTS (B + C = E)				**39 080.85**
TOTAL INDIRECTLY ALLOCATABLE VARIABLE COSTS (D)				**1 374.92**
TOTAL ALLOCATABLE VARIABLE COSTS (D + E = F)				**40 455.77**
GROSS MARGIN ABOVE TOTAL ALLOCATABLE VAR. COSTS (A - F)				**54 544.23**
MARGIN ABOVE DIRECTLY ALLOCATABLE VARIABLE COSTS (A - E)				**55 919.15**

The gross margins obtained per hectare above the TAVC for the crop grown under dryland and irrigated conditions and marketed in the three methods are summarized in Table 8.9.

TABLE 8.9 Gross margins above total allocatable variable costs for the crop grown under irrigated or dryland conditions and marketed in three methods

Marketing method	Dryland	Irrigated
	(R ha^{-1})	
Green pods sold in 10 kg vegetable pockets	17 117.12	32 337.98
Marketable green pods sold in 10 kg vegetable pockets and 1-seeded pods shelled and sold as green beans in plastic punnets	27 260.67	38 109.23
Green beans sold in plastic punnets	36 921.67	54 544.23

The return on investment (ROI) for the crop grown under dryland and irrigated conditions and marketed in the three methods is presented in Table 10. As gross margin ha^{-1} above the TAVC increased, ROI increased.

TABLE 8.10 Return on investment for the crop grown under irrigated and dryland conditions and marketed in three methods

Marketing method	Dryland	Irrigated
	(%)	
Green pods sold in 10 kg vegetable pockets	75.13	100.24
Marketable green pods sold in 10 kg vegetable pockets and 1-seeded pods shelled and sold as green beans in plastic punnets	107.80	110.62
Green beans sold in plastic punnets	126.97	134.53

8.5 DISCUSSION

With the costs and marketing prices used in this economic exercise, the indications are that the crop would be economically viable in all six scenarios presented (Table 8.9). The gross margins ha^{-1} above TAVC obtained when the crop was grown under dryland conditions and marketed mainly as green pods are similar to or higher than those predicted by Ernst (2001) and Shockley *et al*. (2012). The gross margins ha^{-1} above TAVC are lower than those estimated in September 2015 by the Agricultural Economics and Marketing Section of the KZNDARD for an 8 t ha^{-1} yield of irrigated green beans (*Phaseolus vulgaris* L.) sold at R11 448.54 t^{-1}, where a gross margin ha^{-1} above TAVC of R41 934.76 was obtained. However, the gross margins ha^{-1} above TAVC for vegetable soybean were considerably higher than the gross margins ha^{-1} above TAVC for grain soybeans, which were R2 781.05 and R8 231.44 for a 2.0 t ha^{-1} dryland yield and a 3.5 t ha^{-1} irrigated yield, respectively, when sold at R5 358.25 per ton.

The higher yields obtained from irrigating the crop resulted in greater profitability, indicating that the crop should be irrigated to maximize profitability per unit area. When irrigation is applied during the reproductive stages, and especially during pod-fill, higher yields will be obtained (Demirtaş *et al*., 2010; Comlekcioglu and Simsek, 2011; Popovic *et al*., 2013; Adeboye *et al*., 2015). Adequate soil moisture at harvesting promotes the pod‟s market quality and may prolong the harvest period (Sharma, 2013). Water stress will adversely affect the seed size and sugar content, which are important marketing requirements (James, 2007). Mentreddy *et al*. (2002) and Comlekciouglu and Simsek (2011) reported green pod yields up to 22 t ha^{-1} and 34 t ha^{-1}, respectively, which are double and triple the yields used in the calculations here.

Therefore, higher yields than those used in this exercise may be achieved with irrigation. The lowest gross margin above TAVC and the lowest return on investment (ROI) were obtained when the dryland-produced crop was marketed as ungraded green pods only (Tables 8.9 and 8.10). These values were considerably lower than those obtained with the other production and marketing combinations. The highest gross margin above TAVC and the highest ROI are obtained when an irrigated crop is sold as fresh green beans in plastic punnets.

For quality purposes, the green pods should contain at least two beans and be free of defects (Nelson *et al*., 2002; Born, 2006; James, 2007). Under good conditions at least 80% of the pods will contain ≥ 2 beans pod^{-1}. Sharma and Kshattry (2013) reported a mean of 86.4% pods with two or more beans for seven cultivars evaluated under irrigation. Although 70% of the dryland-produced pods were considered to be marketable (≥ 2 beans pod^{-1}) in this exercise, this figure will vary depending on the cultivar used and the environmental conditions experienced during the season. In cultivar evaluation trials conducted at Cedara with four plantings and twenty cultivars, a mean of 68.7% of the pods were considered marketable, whilst the range for the cultivars was from 56.3% to 76.9%. Hail damage to the plants in two of the plantings resulted in reductions in the percentage marketable pods.

Seeding rate may also have an effect on the percentage marketable pods. In seeding rate trials conducted at Cedara under rain-fed conditions with medium- and long-season vegetable soybean cultivars, no significant differences in yield were measured with seeding rates from 50 000 to 250 000 seeds ha^{-1}. Soybean plants adjust to low plant populations by producing more branches and therefore more pods $plant^{-1}$ (Lee *et al*., 2008; Suhre, 2012). Higher seeding rates than those used in this exercise will be required for short-season cultivars (Edwards *et al*., 2005; Christmas, 2008) and for medium- to long-season cultivars when planted late in the season, but not for short-season cultivars, which produce more stable yields at late planting dates (Lee *et al*., 2008; Zhang *et al*., 2010). Therefore higher seed costs will be incurred.

Marketing the crop as green beans is considerably more profitable than selling the crop as green pods, due to the higher price. However, growers will need to secure buyers of the whole crop when supplied as fresh green beans in plastic punnets. Producers must therefore consider which markets to target. Japanese consumers prefer edamame on the plant or in the pod, while fresh shelled green beans are preferred by the Chinese consumers. Small-scale producers will probably want to target fresh markets, because the machinery required to shell the beans may be expensive and unavailable in South Africa. Freshness of the produce is the key to gaining the Chinese and other markets. To ensure freshness the market radius should be limited (Born, 2006; Mentreddy *et al*., 2002).

As reported by Born (2006), the major cost of production was the number of labour days required to harvest and pack the products. The use of a green bean (*Phaseolus vulgaris* L.) harvester may reduce the production costs by 25%. However, the purchase price of this machine will have to be considered and calculations made to determine whether the outlay of purchasing a harvester will be cost effective in terms of the number of hectares planted to vegetable soybean each season. The operating costs will have to be budgeted for and included in the cost of production. Furthermore, as reported by Zandonadi *et al*. (2009), the efficiency of using a green bean harvester for harvesting vegetable soybean can vary from 54% to 85%, depending on the plant height and row spacing. Therefore, yield losses and lower net returns will occur, especially if the lower pods are below the harvester‟s cutting height.

South Africa has one of the highest unemployment rates in the world. On 27 October 2015 the unemployment rate in South Africa was 25.5% (http//www.tradingeconomics.com/south-africa/unemployment-rate). Using labour for harvesting and packing the crop will create job opportunities, which, in turn, will assist in alleviating poverty. The labour will be exposed to the crop and become aware of its potential as a high-protein food source and economically viable crop. Rural small-scale farmers may then become encouraged to grow the crop for their own household consumption (food security) and may sell surpluses to people in the neighbourhood. To avoid labour costs and the time involved with removing the pods from the plants, whole above-ground plants or plants pulled out of the ground could be sold in bundles of four to six plants (Born, 2006).

As the crop is poorly known in South Africa and as there are few Chinese and Japanese people in the country to supply edamame to, an awareness campaign informing the public of the nutritional qualities, health benefits and uses would be necessary. Edamame can be eaten as a snack or be included in salads, stir-fries, soups and stews (Mentreddy *et al*., 2002; Duppong and Hatterman-Valenti, 2005; Sanchez *et al*., 2005; Zhang and Kyei-Boahen, 2007). If demand for the crop increases, then the prices obtained will increase and therefore a greater net return on investment can be achieved.

However, growers will need to supply the market over as long a period as possible during the year. The harvest window can be narrow, less than a week, depending on the locality and the climatic conditions (Duppong and Hatternman-Valenti, 2005; Hamilton, 2007). Edamame should be harvested when the seed size is maximized, but before any yellowing of the pods occurs. This is critical for optimum texture and flavor (Herman, 2010). An indicator that this is about to happen is when the lower leaves of the plant start to yellow. Serial plantings and/or planting cultivars with varying growing-season lengths will extend the marketing period and maximize profitability (Rao *et al.*, 2001; Herman, 2010; Zhang *et al.*, 2010). Supplying the market regularly will be further achieved if the pods and beans are frozen using quick freeze technologies. Frozen edamame can be stored for long periods of time (Nelson *et al*., 2002). Chilling beans for 3 to 10 hours after harvest helps preserve quality (Born, 2006). Fresh pods and beans can be held in excellent conditions for several days using a cold chain technology similar to that deployed for other vegetables (James, 2007).

In 2013, plastic punnets containing 80 g of green edamame beans produced in Kenya were sold in a major food store in Howick, KwaZulu-Natal, at R10.00 per punnet. This equated to a price of R125.00 kg^{-1}, and a gross return of R1,250,000 ha^{-1} (at a yield of 10 t ha^{-1}) giving an indication of the potential value of edamame. However, farmers considering producing edamame must be aware that the crop requires greater farming skills, is labour intensive and has a tight harvesting window.

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DISSERTATION OVERVIEW

Edamame (*Glycine max* (L.) Merrill) originated in China, but is now grown in many other parts of the world due to its tastiness and the known health benefits of soybean isoflavones (Duppong and Hatterman-Valenti, 2005; Sciarappa *et al*., 2007). However, edamame occupies < 2% of global soybean production (Keatinge *et al*., 2011), which was 276.4 million tons in the 2013/14 season (Geohive, last accessed 26/08/2015). Although 784 500 tons of grain soybean were produced in South Africa in the 2013/14 season (Dredge, 2014), there is no known commercial production of edamame.

As edamame is poorly known in South Africa, an extensive awareness campaign on how to produce, market and use the crop will be required. However, prior to that, in-depth research on the crop‟s requirements, adaptability and productivity is required. Therefore, the objective of this study was to conduct research on edamame on the Cedara and Dundee Research Stations in KwaZulu-Natal to determine:

a) The optimal seeding rate
b) The adaptability and yield of a range of cultivars grown under rain-fed conditions
c) The crop‟s requirements of phosphorus and potassium to maximise yield
d) The use of fungicides and a bio-fungicide as seed coatings to improve plant stand and yield
e) The effect of various *Bradyrhizobium japonicum* inoculants on nodulation and yield
f) The economic viability of producing the crop.

As mentioned by Lee *et al*. (2008) and Suhre (2012), yields of grain soybean and edamame are relatively insensitive to plant population, because the plants produce more branches containing more pods as the plant population decreases. In the experiments, similar yields were produced by medium- and long-season edamame cultivars at seeding rates from 200 000 to 500 000 seeds ha^{-1}. This result prompted evaluating cultivars with varying growing-season lengths at seeding rates from 50 000 to 250 000 seeds ha^{-1}. Again, no significant differences in yield were measured between the seeding rates of the medium- and long-season cultivars. However, the short-season cultivar, AGS 292, required a seeding rate of 250 000 seeds ha^{-1} to produce similar yields to those obtained by the other cultivars. Due to the short stature of AGS 292, the plants did not canopy in the 0.75 m wide rows and therefore narrower inter-rows are recommended to prevent weed competition. The cultivars Lightning, AGS 353 and AGS 354 yielded optimally at 50 000, 75 000 and 150 000 seeds ha^{-1}, respectively, indicating that high seeding rates are not necessary. In fact, low seeding rates are more beneficial, because seed costs are reduced and a higher percentage of pods containing ≥ 2 large beans are produced, therefore meeting the marketing requirements for green pods. In addition, when selling the whole plant, the appearance of the product will be improved by the abundance of pods on the plant.

The cultivars evaluated displayed good adaptability to the environmental conditions experienced in the KwaZulu-Natal Midlands. Overall, the longer-season cultivars produced higher green pod and bean yields than the short-season cultivars. Poor seed quality, which resulted in low plant populations, and hail damage both affected the performance of the shorter-season cultivars and therefore the mean yields produced by these cultivars were not a true reflection of their potential. However, in the 2011/12 season, when the plant populations and growing conditions were more suitable for the short-season cultivars, green pod yields above 10.5 t ha^{-1} were obtained by these cultivars and were not significantly different to the yields of the other cultivars. As a continuous supply of edamame to food stores will be required and because the harvest window is narrow, it is recommended that either a range of cultivars with varying growing-season lengths be planted and/or that sequential plantings be done (Carson *et al*., 2011; James, 2007). Based on the results obtained, the following cultivars are recommended for the KwaZulu-Natal Midlands:

a) AGS 292 and/or AGS 329, which are short-season cultivars (80-81 days after planting (DAP) to green pod harvest).
b) AGS 457 (93 DAP), AGS 458 (96 DAP) and AGS 423 (99 DAP), which are medium-season cultivars.
c) AGS 354 (105 DAP) and/or AGS 353 (106 DAP), which are medium- to long-season cultivars.
d) AGS 352 and Lightning (125 DAP), which are long-season cultivars, but these cultivars have smaller seeds than the other cultivars.

Although the experiments were conducted under rain-fed conditions, when sufficient rain was received during pod-fill, high yields were obtained, indicating that supplementary irrigation, especially during the reproductive growth stages, will result in higher yields and greater profitability (James, 2007; Comlekcioglu and Simsek, 2009; Demirtaş *et al.*, 2010). The effect of hail damage on yield was dependent upon the extent of the damage and the growth stage of the crop at the time. Hail damage at flowering resulted in lower yields. The longer the recovery period after hail damage during the vegetative growth stages, the higher the yields will be.

In addition to having sufficient moisture, high yields and good quality of edamame will be achieved if the nutritional needs of the crop are met. Where soil fertility is sub-optimal, soybean reacts well to directly applied fertilizer, but it also has the ability to utilize residual fertilizer from well fertilized or fertile soils (Liebenberg, 2012). For soybean, the target soil level for phosphorus (P) was 12 mg L^{-1} for the Hutton soil where the fertility experiment was conducted. After application of the fertilizer treatments, analyses of the soil samples taken immediately after planting revealed that the P levels were between 10.5 and 11.9 mg P L^{-1} when 60 kg P ha^{-1} had been applied. At this application rate, significantly higher pod yields were obtained compared to when 0 and 30 kg P ha^{-1} were applied.

The analyses of the soil samples taken immediately after planting in the second season indicated that possible luxury uptake of potassium (K) by the plants occurred during the first season, especially at the higher K application rates. In KwaZulu-Natal grain soybean plants do not respond to K fertilizer applications when the soil status is above 80 – 90 mg kg^{-1} (Farina, 1992; Liebenberg, 2012). However, to allow for luxury uptake and to meet the K requirements of maize, which is usually planted after soybean, the target soil test for K was 100 mg L^{-1}. Overall, K applications above 40 kg ha^{-1} did not result in significantly higher green pod yields. The soil tests for K at planting were between 65 and 74 mg L^{-1} at the K application rate of 40 kg ha^{-1}. A significant interaction was measured for green pod yield between the cultivars and K application rates, with AGS 353 requiring 40 kg K ha^{-1} and Lightning requiring 160 kg K ha^{-1} to optimize production, indicating that cultivars may vary in their K requirements to yield optimally. No significant interaction was measured for green pod yield between the cultivars and P application rates. Overall, the highest green bean yield was obtained by the combination of 60 kg P ha^{-1} and 120 kg K ha^{-1}, indicating the importance of adequate nutrition for high vegetable soybean yields. However, the economic benefit of applying high amounts of fertilizer to produce optimal yields will have to be determined.

The application of the fungicides, thiram and captan, as seed coatings at planting improved plant stand above the Control treatment (no fungicide), whilst the bio-fungicide, Eco-T®, did not. However, despite the higher plant population, no significant differences in yield were measured. As mentioned above, edamame plants adjust their growth habits to maximize yield and therefore applying fungicides would be an unnecessary expense, unless there is a known history of soil-borne diseases in the land or the quality of the seed is unsatisfactory. It was reported by Campo *et al*. (2009), Zilli *et al*. (2009) and Liebenberg (2012) that thiram and captan can severely reduce the rhizobial population. However, the number of nodules $plant^{-1}$ and the percentage active nodules on the plants where thiram and captan had been applied were similar to those of plants treated with Eco-T® and the Control treatment, indicating that they did not affect nodulation in these experiments. In fact, the AVRDC – The World Vegetable Center, recommends the use of these products for the protection of edamame seed against soil-borne diseases (Lal *et al*., 2001).

As soybean is a legume, it requires a symbiotic relationship with *Bradyrhizobium*-bacteria to produce optimally. These bacteria are not indigenous to South African soils and therefore inoculation is essential in lands that have not been previously planted to soybean. The results indicated that even though soybean had not been grown on the Cedara Research Station sites in the previous ten years, the rhizobial populations were healthy and therefore inoculation was not necessary. However, as a result of applying the inoculants, Soycap and Eco-Rhizsoy®, significantly higher yields were produced than the Control treatment. The cost of the inoculant is low and to ensure that a healthy rhizobial population remains in the field, inoculation is recommended. Some research suggests that successive inoculant applications can increase yields by 4 to 5%, but usually the response is only 1 to 2% (Conley and Christmas, 2006), which will warrant the cost of the inoculant. Residual biological nitrogen from the soybean crop can have an average yield increasing effect of 13% on a subsequent maize crop (Porter *et al*., 1997). If nodulation is poor, which may occur under very hot and dry conditions or when the crop has been waterlogged, the application of nitrogen may be necessary. The application of nitrogen may also be necessary when the clay content of the soil is below 10% (Liebenberg, 2012). High levels of nitrate in the soil or large applications of nitrogen will reduce nodule formation and activity and it will accelerate nodule senescence, resulting in lower yields (Campo *et al*., 2010; Ohyama *et al*., 2011; Emam and Rady, 2014).

The crop can be harvested using a green bean (*Phaseolus vulgaris* L.) harvester, but losses may occur depending on the plant height and spacing (Born, 2006). Alternatively, labour can be used for harvesting, but will be expensive. South Africa has one of the highest unemployment levels in the world and therefore using labour to harvest, grade and pack the crop will create job opportunities and assist in alleviating poverty.

The crop can be marketed in various ways, namely as fresh green pods, green beans or in bundles of whole plants, with or without the roots, depending on the market. Marketing the crop as green beans in plastic punnets at R20.00 kg^{-1} produces the highest gross margin above total allocatable variable costs (TAVC), whilst selling the crop as green pods at R7.00 kg^{-1} returns the lowest gross margin, but is still economically viable, depite the high labour costs. Even with a conservative green pod yield of 7 t ha^{-1} produced under dryland conditions, a considerably higher gross margin above TAVC is produced than with grain soybean. Variations in both the yield and market price of edamame, as a result of the growing conditions and the demand for the crop, respectively, will affect profitability. Creating a public awareness of the crop‟s requirements, nutritional qualities and uses is therefore essential to establish a demand. Taste tests conducted by the multi-racial staff of the KwaZulu-Natal Department of Agriculture and Rural Development at the Cedara Research Station indicated that edamame was well-liked, particularly when lightly salted.

Current research work

- In the 2014/15 season hail destroyed the trial determining the effect of seeding rate on cultivars with varying growing-season lengths. The trial will be repeated in the 2015/16 season to confirm the results obtained in previous seasons.
- Hail also destroyed the trial determining the influence of phosphorus and potassium applications on the production of two edamame cultivars. The trial will be repeated in the 2015/16 season. The results obtained from the Plant and Feed Laboratories in the 2012/13 and 2013/14 seasons will be statistically analysed for the P and K levels in the plant residues, pods and beans and for the crude protein and fat contents in the beans.

Proposed future research work

- Determine the optimum combination of row spacing and seeding rate for short-season vegetable soybean cultivars.
- Genetic x environment studies need to be conducted at various sites in KwaZulu-Natal and in other areas of South Africa to determine the most suitable cultivars for each area.
- Breed better adapted and higher yielding cultivars. Although vegetable soybean cultivars are bred specifically for consumption as a green bean, early pod shattering is a problem and therefore better resistance to shattering would be an advantage to seed producers. As variable weather conditions are experienced in South Africa and as a large part of the country is warmer and drier than the KwaZulu-Natal Midlands, cultivars with heat and drought tolerance would be more suitable for rain-fed production areas. To reduce chemical costs, breeding cultivars with tolerance or resistance to various diseases, such as soybean rust (*Phakopsora pachyrhizi* H. Syd and P. Syd), will be beneficial.

- To supply the market with edamame for as long a period as possible, serial planting is an option. Therefore, a planting date trial with cultivars having varying growing-season lengths would determine the number of days to green pod harvest and yield potential, particularly at early and late planting dates.
- Further taste testing sessions with a range of the higher yielding cultivars must be conducted with the racial groups in South Africa. As the crop is poorly known in South Africa, the public needs to be exposed to it. Small-scale and commercial farmers need to be aware that edamame is a potential alternative crop with economic and crop rotation benefits. Demonstrations may have to be conducted on farms and in rural communities.

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APPENDIX

The following appendices apply to Chapter 4:

Appendix 1 Number of branches plant^{-1}

A significant interaction was measured with the cultivars and seasons for the number of branches plant^{-1} (Table 1.1). The hail storm on 31/12/2012 broke the main-stem off many of the plants in 2012/13 (2nd) season, resulting in a significantly lower mean number of branches plant^{-1} than in the other two seasons. Axillary stems then developed as main-stems, thus reducing the number of branches plant^{-1}. The longer-season cultivars produced more branches plant^{-1} than the shorter-season cultivars (Table 1.2).

TABLE 1.1 ANOVA table of the number of branches plant^{-1} for the cultivars and seasons for three trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	16.88	**	0.28	
Season	66.63	**	0.61	
Cultivar x season	4.31	**	1.06	17.2

TABLE 1.2 Branches measured for the various cultivars in the three seasons

Cultivar	Season 2011/2012	2012/2013 (1st)	2012/2013 (2nd)	Mean
	(number plant^{-1})			
AGS 292	3.19	2.63	1.83	**2.55**
AGS 329	3.17	2.73	1.90	**2.60**
AGS 437	2.50	3.90	2.23	**2.88**
AGS 425	2.86	3.50	2.70	**3.02**
AGS 418	2.83	4.10	2.30	**3.08**
AGS 434	3.75	2.73	3.00	**3.16**
AGS 423	3.33	2.90	3.67	**3.30**
AGS 457	3.20	4.37	2.53	**3.37**
AGS 458	4.11	3.90	2.70	**3.57**
AGS 382	4.22	4.50	2.20	**3.64**
AGS 432	4.14	3.37	3.63	**3.71**
AGS 335	3.50	4.10	3.70	**3.77**
AGS 429	4.75	3.87	3.27	**3.96**
TANBAGURO	4.83	3.87	3.70	**4.13**
TANBA	5.19	4.07	3.60	**4.29**
AGS 440	4.86	5.47	2.60	**4.31**
AGS 354	6.25	4.03	4.17	**4.82**
LIGHTNING	7.17	5.03	2.93	**5.04**
AGS 353	6.38	4.50	4.43	**5.10**
AGS 352	7.72	5.17	4.80	**5.90**
Mean	**4.40 a**	**3.94 b**	**3.10 c**	**3.81**
F value	15.99	6.92	3.79	4.31
P value	**	**	**	**
LSD (P<0.05)	1.11	0.87	1.24	1.06
CV %	15.0	13.4	24.3	17.2

Appendix 2 Percentage seedless pods

A significant interaction with the seasons and cultivars was measured for percentage seedless pods (Table 2.1). Mean percentage seedless pods were significantly higher in both plantings in the 2012/13 season than in the 2010/11 and 2011/12 seasons (Table 2.2). This may have been due to the effect of the hailstorm. The brown-seeded cultivars, AGS 457 and AGS 458, produced the lowest mean percentage seedless pods. The black-seeded cultivars, Tanba and Tanbaguro, produced significantly higher percentages of seedless pods in the 2012/13 (1st) season than all the other cultivars in all the other seasons.

TABLE 2.1 ANOVA table of the percentage seedless pods for the cultivars and seasons for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Cultivar	45.29	**	2.0	-
Season	122.84	**	1.3	-
Cultivar x season	8.40	**	4.0	23.9

TABLE 2.2 Seedless pods recorded for the various cultivars in the four seasons

			Season		
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st) (%)**	**2012/2013 (2nd)**	**Mean**
AGS 458	3.6	3.1	7.2	2.4	**4.1**
AGS 457	5.9	1.8	6.7	3.4	**4.5**
AGS 440	2.8	0.5	11.6	3.4	**4.6**
AGS 382	4.9	4.1	6.0	8.4	**5.8**
AGS 434	5.8	1.9	9.4	10.6	**6.9**
AGS 425	7.5	3.8	8.0	11.2	**7.6**
AGS 353	2.9	3.8	11.7	12.2	**7.7**
AGS 354	1.9	4.0	16.5	12.1	**8.6**
AGS 418	10.2	4.8	11.1	9.3	**8.9**
AGS 437	8.5	3.8	19.0	6.3	**9.4**
AGS 329	11.0	2.6	17.7	7.2	**9.6**
AGS 429	5.1	4.7	18.2	11.8	**9.9**
AGS 292	10.3	3.4	15.8	10.5	**10.0**
AGS 423	5.1	4.7	16.8	16.7	**10.8**
AGS 335	13.6	3.5	8.2	24.4	**12.5**
LIGHTNING	4.4	10.3	18.6	19.8	**13.3**
AGS 432	8.3	12.9	23.6	15.9	**15.2**
TANBAGURO	14.5	12.5	33.1	14.9	**18.7**
TANBA	16.9	11.0	32.0	15.6	**18.9**
AGS 352	13.0	19.8	24.4	23.5	**20.2**
Mean	**7.8 c**	**5.8 d**	**15.8 a**	**12.0 b**	**10.4**
F value	6.27	19.6	30.39	20.97	8.40
P value	**	**	**	**	**
LSD (P<0.05)	4.93	3.15	4.11	3.87	4.0
CV %	38.3	32.6	15.8	19.5	23.9

The figures highlighted in red indicate a significantly high percentage of seedless pods.

Appendix 3 Percentage one-seeded pods

A significant interaction was measured between the cultivars and seasons for percentage one-seeded pods (Table 3.1). Mean percentage one-seeded pods was highest in the 2010/11 season and lowest in the 2011/12 season (Table 3.2). AGS 425 and AGS 429 produced the lowest mean percentage one-seeded pods, whilst AGS 437, Tanba and Tanbaguro produced the highest mean percentages of one-seeded pods. The short-season cultivars AGS 392, AGS 292 and AGS 382 produced significantly high and low percentages of one-seeded pods in the 2010/11 and 2011/12 seasons, respectively. AGS 418 produced a low percentage of one-seeded pods in the 2011/12 season.

TABLE 3.1 ANOVA table of the percentage one-seeded pods for the cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	16.89	**	3.2	-
Season	32.02	**	2.2	-
Cultivar x season	4.29	**	6.6	14.4

TABLE 3.2 One-seeded pods recorded for the various cultivars in the four seasons

Cultivar	2010/2011	2011/2012	Season 2012/2013 (1st) (%)	2012/2013 (2nd)	Mean
AGS 425	16.5	17.0	26.0	25.4	**21.2**
AGS 429	25.1	20.9	20.7	19.6	**21.6**
AGS 352	25.7	24.4	21.7	19.7	**22.9**
AGS 335	27.5	17.4	24.6	24.9	**23.6**
AGS 418	27.9	13.2	33.2	22.7	**24.2**
AGS 423	19.6	21.3	29.8	26.0	**24.2**
AGS 440	25.7	17.5	29.0	27.0	**24.8**
LIGHTNING	31.6	23.2	26.5	19.7	**25.3**
AGS 434	28.4	19.4	27.6	26.2	**25.4**
AGS 458	31.6	22.8	26.8	22.0	**25.8**
AGS 354	32.6	22.3	26.2	30.8	**28.0**
AGS 353	30.4	23.3	30.1	29.3	**28.3**
AGS 432	32.1	29.1	27.8	25.9	**28.7**
AGS 457	37.4	24.7	29.9	27.4	**29.9**
AGS 382	42.4	17.2	33.4	29.7	**30.7**
AGS 292	43.8	19.6	29.6	30.1	**30.8**
AGS 329	47.4	19.8	28.0	34.6	**32.4**
TANBAGURO	38.4	36.2	29.4	33.0	**34.3**
TANBA	39.7	39.3	30.2	32.8	**35.5**
AGS 437	46.9	32.4	33.2	40.6	**38.3**
Mean	**32.5 a**	**23.1 c**	**28.2 b**	**27.4 b**	**27.8**
F value	9.15	7.49	2.96	8.29	4.29
P value	**	**	**	**	**
LSD (P<0.05)	8.14	7.00	5.66	5.41	6.6
CV %	15.1	18.3	12.1	12.0	14.4

The figures highlighted in red and green indicate cultivars with high or low percentages of one-seeded pods, respectively.

Appendix 4 Shelling percentage

A significant interaction with the cultivars and seasons was measured for shelling percentage (Table 4.1). Mean shelling percentage was significantly higher in the 2010/11 and 2011/12 seasons than in both plantings in the 2012/13 season (Table 4.2). Mean cultivar shelling percentage ranged from 45.8% (AGS 292) to 55.7% (Lightning). The longer-season cultivars tended to produce higher shelling percentages than the shorter-season cultivars. However, the shorter-season cultivar, AGS 440, produced a high mean shelling percentage due to its large seed size and high percentage export marketable pods, which resulted from consistently low plant populations.

TABLE 4.1 ANOVA table of the shelling percentage (bean mass to pod mass) for the various cultivars and seasons for four trials

Source of variation	**F value**	**P value**	**LSD (P<0.05)**	**CV %**
Cultivar	25.10	**	1.54	-
Season	150.50	**	0.93	-
Cultivar x season	4.58	**	3.10	3.7

TABLE 4.2 Shelling percentage recorded for the various cultivars in the four seasons

			Season		
Cultivar	**2010/2011**	**2011/2012**	**2012/2013 (1st) (%)**	**2012/2013 (2nd)**	**Mean**
AGS 292	46.8	50.3	42.3	44.0	**45.8**
AGS 329	47.3	51.4	41.2	43.8	**45.9**
AGS 335	45.7	52.6	45.8	42.0	**46.5**
AGS 434	52.1	51.7	44.1	44.8	**48.2**
AGS 437	50.8	51.6	41.8	48.5	**48.2**
AGS 429	55.2	52.6	44.4	46.7	**49.8**
AGS 432	56.3	50.2	41.7	51.3	**49.9**
AGS 458	51.3	52.1	47.1	49.6	**50.0**
AGS 423	53.9	54.2	46.7	49.0	**51.0**
AGS 352	52.6	54.2	49.4	48.7	**51.2**
AGS 457	53.6	53.0	47.9	52.8	**51.8**
AGS 382	57.1	51.2	49.5	49.7	**51.9**
AGS 425	56.7	51.9	49.3	50.6	**52.1**
AGS 418	58.3	54.4	47.8	48.2	**52.2**
TANBAGURO	52.8	57.9	50.9	51.3	**53.2**
AGS 354	58.2	56.2	46.6	52.3	**53.3**
TANBA	52.0	57.3	51.3	52.4	**53.3**
AGS 353	58.8	56.6	46.7	51.4	**53.4**
AGS 440	60.3	55.2	48.6	49.5	**53.4**
LIGHTNING	55.9	60.7	54.3	52.1	**55.7**
Mean	**53.8 a**	**53.8 a**	**46.9 c**	**48.9 b**	**50.8**
F value	4.77	23.45	22.05	29.08	4.58
P value	**	**	**	**	**
LSD (P<0.05)	5.39	1.66	2.14	1.68	3.10
CV %	6.1	1.9	2.8	2.1	3.7

Appendix 5 Seed yield

A significant interaction was measured between the cultivars and seasons for seed yield (Table 5.1). Mean seed yield was significantly higher in the 2012/13 (2nd) season than in the 2010/11 and 2011/12 seasons (Table 5.2). Mean seed yield ranged from 1.8 t ha^{-1} for AGS 437 to 3.1 t ha^{-1} for AGS 352. The longer-season cultivars produced higher mean yields than the shorter-season cultivars. However, in the 2011/12 season the yields of the longer-season cultivars were affected by the low rainfall received during grain-fill. Mean seed yield was 23.7% of green pod yield and 46.5% of green bean yield.

TABLE 5.1 ANOVA table of the seed yield for the various cultivars and seasons for four trials

Source of variation	F value	P value	LSD (P<0.05)	CV %
Cultivar	17.19	**	67.9	-
Season	18.56	**	282.1	-
Cultivar x season	4.07	**	576.7	14.4

TABLE 5.2 Seed yield recorded for the various cultivars in the four seasons

Cultivar	2010/2011	2011/2012	Season 2012/2013 (1st) (kg ha^{-1})	2012/2013 (2nd)	Mean
AGS 437	1 539	2 475	1 453	1 659	**1 781**
AGS 440	1 338	2 262	1 649	1 869	**1 779**
AGS 425	1 244	2 121	2 107	1 828	**1 825**
AGS 292	916	2 744	1 866	1 969	**1 874**
AGS 329	1 164	2 664	1 875	1 855	**1 889**
AGS 335	1 457	1 798	2 117	2 281	**1 913**
AGS 418	1 835	1 976	2 379	2 234	**2 106**
TANBA	1 256	1 727	2 626	2 839	**2 112**
AGS 382	1 507	2 222	2 253	2 510	**2 123**
AGS 434	2 012	2 380	2 447	2 610	**2 362**
TANBAGURO	1 725	1 977	2 571	3 269	**2 386**
AGS 458	1 925	2 388	2 530	2 708	**2 388**
AGS 457	2 066	2 753	2 386	2 358	**2 391**
AGS 432	2 215	2 060	3 109	2 555	**2 485**
AGS 423	2 136	2 464	2 577	2 833	**2 503**
AGS 429	2 278	2 491	2 893	2 821	**2 621**
AGS 354	2 306	2 415	2 665	3 442	**2 707**
AGS 353	2 581	2 540	2 713	3 376	**2 802**
LIGHTNING	2 160	2 296	3 207	3 780	**2 861**
AGS 352	2 001	2 638	3 581	4 314	**3 134**
Mean	**1 783 c**	**2 320 b**	**2 450 ab**	**2 655 a**	**2 302**
F value	7.01	4.26	7.65	8.66	4.07
P value	**	**	**	**	**
LSD (P<0.05)	493.6	429.3	544.1	687.5	576.7
CV %	16.7	11.2	13.4	15.6	14.4

The figures in red and green indicate the lowest and highest seed yields obtained, respectively.