

**MORPHO-PHYSIOLOGICAL VARIATIONS AND YIELD ASSOCIATED  
WITH PLANTING DENSITY IN SOYBEAN (*Glycine max.* (L) Merrill)**

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**DECLARATION**

I **SICHILIMA ISAAC** do hereby declare that this dissertation represents my own work and that, to the best of my knowledge, it has not been previously submitted for the award of a degree at this or any other University.

Signed.....

Date.....

**APPROVAL**

The University of Zambia approves this dissertation of Sichilima Isaac as fulfilling the requirements for the award of the degree of Master of Science in Agronomy.

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## ABSTRACT

Understanding morpho-physiological factors associated with yield decline at high density in soybean (*Glycine max* L.) can assist in optimizing productivity and seed quality. The objective of this study was to determine effects of different spacing on development and seed quality. The study tested the concept of yield plasticity. Five varieties that included determinate (SC Safari, Dina and Magoye) and indeterminate (Kaleya and Pan 1867) and three densities (300,000, 400,000 and 550,000 plants/ha) were used. A randomized complete block design arranged in 2 factor- factorial with variety and plant density and 4 replications was used. The experiment was done at Seed Control and Certification Institute in Chilanga, Zambia in 2015. Parameters assessed included: height, branches/plant, chlorophyll, nitrogen, 50 % flowering, pod-fill time, maturity duration, biomass, seed quality, yield and yield components. Significant effects for variety were present for all parameters while plant density effects were highly significant for number of branches/plant ( $p < 0.001$ ), biomass yield ( $p < 0.001$ ), pods/plant ( $p < 0.001$ ), seeds/pod ( $p < 0.001$ ) and yield ( $p \leq 0.05$ ). Interaction effects were observed for pods/plant and seeds/plant. Traits positively and significantly correlated to yield were height, canopy biomass yield, pods/plant and seeds/plant. Biomass, pods/plant, seeds/plant and 100 seed weight contributed significantly to total variation of grain yield at  $R^2 = 85.3$  %. Plant height, biomass yield, number of pods/plant, number of seeds/plant and hundred seed weight were critical parameters determining yield elasticity. Kaleya, Pan 1867 and Dina appear more tolerant of planting at high density.

## **DEDICATION**

To Nonde, Kundananji and Mupelwa for the love, care and patience. May the desires of your hearts be fulfilled

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## TABLE OF CONTENTS

<b>DECLARATION</b> .....	<b>i</b>
<b>APPROVAL</b> .....	<b>ii</b>
<b>ABSTRACT</b> .....	<b>iii</b>
<b>DEDICATION</b> .....	<b>iv</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>v</b>
<b>CHAPTER 1: INTRODUCTION</b> .....	<b>1</b>
1.1 Introduction .....	1
1.3 Justification of study .....	3
<b>CHAPTER 2: LITERATURE REVIEW</b> .....	<b>5</b>
2.1 Origin, distribution and domestication .....	5
2.2 Taxonomical and Botanical characteristics of Soybean.....	5
2.3 Climatic, Soil and Other Requirements for Soybean growth.....	6
2.4 Plant Development.....	7
2.5 Threats and challenges to production.....	10
2.5.1 Common biotic stresses associated with soybeans.....	10
2.6 Vegetative plasticity.....	12
2.7 Plant competition .....	12
2.7.1 Plant density and yield development.....	13
2.7.2 Plant density, assimilate partitioning and genotypic differences .....	14
2.7.3 Harvest index, respiration and assimilate partitioning .....	14
2.8 Seed quality and effects of plant density.....	15
<b>CHAPTER 3: MATERIALS AND METHODS</b> .....	<b>17</b>
3.1 Location and planting .....	17
3.2 Analysis of soil chemical properties .....	17
3.3 Data Collection and analytical procedures.....	18
3.3.1 Vegetative parameters .....	22

3.3.2	Reproductive parameters .....	23
3.3.3	Seed quality .....	24
3.4	Design and Data Analysis .....	24
<b>CHAPTER 4: RESULTS.....</b>		<b>25</b>
4.1	Soil chemical properties .....	25
4.2	Effects of variety and population density on morpho-physiological traits .....	25
4.3	Effect of genotype and plant population density on number of branches per plant.....	25
4.4	Effect of genotype and plant population density on chlorophyll content .....	29
4.5	Effect of genotype and plant population on nitrogen content.....	29
4.6	Effect of plant population density and genotype on days to 50 % flowering, days to pod filling and days to full maturity .....	29
4.7	Effect of genotype and plant density on biomass yield and biomass canopy yield at harvest .....	32
4.8	Effect of genotype and plant population density on seed yield per plant .....	35
4.8.1	Effect of plant population density and genotype on 100 seed weight.....	38
4.8.2	Effect of genotype and plant population density on yield.....	38
4.9	Effect of genotype and plant density for post-harvest seed quality .....	38
4.10	Relationship among morpho-physiological traits, grain yield and yield components of five soybean genotypes.....	40
4.11	Stepwise multiple regression .....	40
<b>CHAPTER 5: DISCUSSION .....</b>		<b>43</b>
<b>CHAPTER 6: CONCLUSION AND RECOMMENDATIONS .....</b>		<b>49</b>
<b>REFERENCES.....</b>		<b>50</b>
<b>APPENDICES .....</b>		<b>56</b>

## LIST OF TABLES

Table 1: Vegetative and reproductive stages in soybean ( <i>Glycine max</i> ).....	9
Table 2: Soybean ( <i>Glycine max</i> ) materials used in the experimental trial.....	19
Table 3: Characteristics of the five test Soybean ( <i>Glycine max</i> L.) varieties .....	20
Table 4: Soil chemical profile of the experimental site .....	26
Table 5: ANOVA of treatment effects on 5 genotypes of soybeans.....	27
Table 6: Effects of variety and density on height and branches of soybean. ....	28
Table 7: Effects of variety and density on chlorophyll and N-content .....	30
Table 8: Effects on 50 % flower, podding and maturity of soybeans.....	31
Table 9: Effects of variety and density on biomass yield .....	33
Table 10: Effects on number of pods, seeds, 100 seed weight and yield.....	34
Table 11: Effects of genotype and density on vigour and germination .....	39
Table 12: Correlation between yield and variables for soybean .....	41
Table 13: Regression of yield on morpho-physiological traits .....	42

## LIST OF FIGURES

Figure 1: Interaction effect of variety and density on pods per plant. ....	36
Figure 2: Interaction effect of variety and density on seeds per plant .....	37

## **LIST OF APPENDICES**

Appendix 1: Weather data for the 2014/2015 agricultural season.....	56
Appendix 2: Means for the ANOVA morphological and physiological traits.....	57
Appendix 3: Bonferroni test for multiple comparisons.....	60
Appendix 4: Analyses of results in GenStat.....	63
Appendix 5: Field layout at the experimental site.....	85

## CHAPTER 1: INTRODUCTION

### 1.1 Introduction

Soybean (*Glycine max* L. Merrill) is one of the most important sources of food and feed. It is a versatile plant, and exhibiting a high productivity in a wide array of environments (Harold and Fudi, 1992). In addition to being a profitable cash crop, the high protein content (about 40 %) in soybean makes it an important protein source. The crop is useful in rejuvenating soils by fixing atmospheric nitrogen into the soil and improving soil organic matter content (Lubungu et al. 2013).

Soybean serves a variety of functions in the global food chain, ranging from use as edible oil to a source of protein for humans to use in livestock feed. Globally, approximately 87 % of all soybeans are crushed into soy meal and soy oil, with the remaining 13 % used for direct human consumption. The products derived from the soybean crushing process, consist approximately 80 % soy meal for use in animal feed, 1 % vegetable oil for human consumption and 20 % as a biofuel feedstock. Soybean cultivation is highly concentrated within four countries-USA, Brazil, Argentina and China-accounting for almost 90 % of world output while Asia (excluding China) and Africa, the two regions where most of the food insecure countries are located, together account for only 5 % of production of soybean. Among countries classified as undernourished, only India and Bolivia are significant producers of soybeans (IISD, 2014).

More than 216 million tons of soybeans were produced worldwide in 2007, of which 1.5 million was in Africa. Africa imports nearly as much soybean as it produces, exporting about 20,000 tons annually. Nigeria is the largest producer of soybean in sub-Saharan Africa (SSA), followed by South Africa. Low yields (less than 1 ton/ha in tropical Africa) and a shortage of fertilizer constrain the ability of some countries to increase production. Commercial soybean production on large farms takes place in Zambia, Zimbabwe and South Africa. However, it is mostly cultivated by small-scale farmers in other parts of Africa where it is planted as a minor food crop among sorghum, maize, or cassava (IITA, 2009).

In Zambia, the soybean is grown mostly for edible oil extraction and for products such as soya chunks and soya meal. The cake by-product is fed directly to animals

or processed with other ingredients into animal feed stock. Soya by-products provide relatively low cost, high quality protein to feed rations. With a livestock sector projected to increase, soybean demand is anticipated to increase. The growing demand of soya offers significant opportunity for smallholder farmers to improve their cash base (Lubungu et al., 2013).

The recommended planting time for varieties of soybean available in Zambia is December although in region III, planting can be extended into January. The recommended seed rate is 60-110 kg/ha depending on variety giving a final plant population of 350,000 to 400,000 plants/ha (30-40 plants/m<sup>2</sup>) (Miti, 1995). The planting depth is 2 to 3 cm. .

New varieties of soybean are continuously being developed but the production recommendations have largely remained unchanged. It is postulated that further improvement in yield and higher resource use efficiencies (land, water and nutrients) are possible with improved agronomic/management practices (Wallace and Wallace, 1993). Accelerated human population increase and emergence of extreme climate-described as a 'perfect storm' by Godfray et al, (2010) have combined to reduce access to food and other agricultural products. This situation calls for adoption of strategies such as Sustainable Intensification which seeks to increase yields on less amount of land while at the same time avoiding environmental damage. Plant spacing and population reduction at critical growth stages has effects on plant physiological and morphological development and grain quality. Although yield decline at high population densities is known and soybean is known to have significant plant plasticity in terms of yield, the morphological and physiological changes that underlie this decline are not clearly understood.

In soybean, the advantages for higher plant density generally are: increased yield, reduced erosion, increased harvesting efficiency and early crop canopy closure to help control weeds. The relationship between plant density and development is a complex multi factor relationship. The fact that most of the work has been done in the temperate climates also raises many questions that warrant investigation in environments such as the tropics and subtropics where solar radiation fluxes and temperatures are higher (Ball et al., 2000).

The objective of this study was to determine the effects of different plant spacing on whole plant development, yield and seed quality on selected Zambian soybean varieties. It is anticipated that the findings of this study will contribute to the understanding of the effect of different plant densities on plant development seed quality and yield in soybean.

## **1.2 Objectives**

- 1) To determine the effect on plant development and yield of different plant spacing in different soybean varieties.
- 2) To evaluate plant spacing effect on post-harvest seed quality by assessing germination and vigour.

## **1.3 Justification of study**

Most studies to determine the morphological and physiological variations and yield associated with planting density in soybeans have mainly been done in temperate regions. It was important to assess these effects under tropical environments. Additionally, new varieties of soybeans have been bred and introduced in Zambia. However, recommended plant density has largely remained unchanged at between 60-110 kg/ha (Miti, 1995). It is also necessary to assess performance of the new varieties in varying plant densities to ascertain possibility to increase the plant rate in order to intensify production arising from the ever increasing demand for land amid population increase.

## **1.4 Organisation of dissertation**

Chapter One provides an outline about the research, the identified challenge and objectives and the process to be used for the research focus at hand.

Chapter Two focuses on the literature review which highlights the key theories and principles affecting morphological and physiological factors affecting soybean production and productivity.

Chapter Three outlines the quantitative research design, research approach, materials used, data sampling and gathering and analysis.

Chapter Four presents the key result findings arising from the sampled and analysed data.

Chapter Five outlines a discussion of the quantitative results focussing on the most significant parameters.

Chapter Six provides a summary of the research, the main findings, suggested guidelines to improve soybean seed and crop productivity and need for further research.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 Origin, distribution and domestication

Soybean originated in North Eastern China and was domesticated about 1100 BC (Hymowitz and Newell, 1981). From the centre of origin, the soybean spread to southern China, Korea, Japan, and other countries in south-eastern Asia. Soybean was introduced intermittently into the United States in the late 1700s, but it remained a very minor crop grown mostly for forage until the 1920s and 1930s. Most of the early introductions were useful only for forage as the seeds shattered when ripe, making mechanical harvesting impossible (Sleper and Poehlman, 2006).

It is believed that soybean might have been introduced to Africa in the 19th century by Chinese traders along the east coast of Africa (IITA, 2009). The genus *Glycine* contains two subgenera, *Soja* and *Glycine*. The subgenus *Soja* contains two annual species: *Glycine max* and *Glycine soja*. *Glycine max* has never been found growing wild and the wild, annual *Glycine soja* is a progenitor. *Glycine max* and *Glycine soja* are cross- fertile (Sleper and Poehlman, 2006).

Varieties currently being commercially grown in Zambia have been selected from germplasm introduced from the United States Department of Agriculture (USDA), Asian Vegetable Research and Development Programme (AVRDC), International Institute for Tropical Agriculture (IITA), EMBRAPA in Brazil and other agencies (Miti, 1995). Soybean can grow in most parts of the country, except south of Monze and Western Province where moisture is limiting during critical growth stages of plant establishment and pod filling (MACO, 2002).

### 2.2 Taxonomical and Botanical characteristics of Soybean

The cultivated soybean is a legume in the family *Fabaceae*, subfamily *Faboideae*, genus *Glycine* and species, *max*. (Sleper and Poehlman, 2006; ISTA, 2014). Soybean is a hairy annual with an extensive root system, mostly in the top 15 cm of the soil. The tap root, which is slightly larger in diameter than its many branches, may grow as deep as 2 m and adventitious roots grow from the hypocotyl. Modern cultivars are erect, bushy plants 20 to 80 cm tall, usually with few primary branches, and no secondaries; but prostrate, freely branching forms do occur (Cobley, 1976).

Soybean is classified as indeterminate, semi-determinate or determinate in growth (Mc Williams et al, 1999). The indeterminate type is adapted to short growing seasons, with flower and seed production proceeding before the soybean plant completes its growth, yet seed maturity for all flowers is normally reached simultaneously. The determinate type is adapted to a long season, in which the soybean plant completes growth before or shortly after flowering is initiated (Sleper and Poehlman, 2006).

### **2.3 Climatic, Soil and Other Requirements for Soybean growth**

Development and yield of soybean are a result of a variety's genetic potential interacting with the environment and farming practices (Mc Williams, 1999). Soybean is a daylength sensitive crop and it is a short day plant. Length of daylight is the principle factor that affects the amount of vegetative growth and onset of the reproductive phase. The ideal situation is that the plants grow to a reasonable size (61 to 91 cm) before they bloom (Martin, 1998). These plants require a relatively short day light period (about 8 to 10 hours) and a continuous dark period of about 14 to 16 hours for initiation of flowering. In short day plants the dark period is critical and must be continuous. If this dark period is interrupted even with a brief exposure of red light (660-665  $\mu\text{m}$  wavelength), the short day plant will not flower. However, the inhibitory effect of red light can be overcome by a subsequent exposure with far-red light (730-735  $\mu\text{m}$  wavelengths) (Jain, 2005).

Plant habit is variable and within any cultivar may depend in part on variation in the duration of growth before flowering because soybean is a reproductively photosensitive short-day plant (Cobley, 1976). Large plants tend to bear a large number of seeds. Thus, seed yield potential per plant is closely related to the day length requirement of the variety and to the season of planting (Martin, 1998). Soybean is adapted to altitudes between 800 to 1,600 m if adequate moisture is available during the growing period. Soil should be moist with temperatures above 20 °C at planting. Optimum growing temperatures is between 20 and 25 °C. Optimum soil pH is 5.0 to 5.2 for the optimum utilization of fertilizers (MACO, 2002). Provided soils are deep and well drained, soybean will grow well on a wide

range of soils varying from loamy sands to clay loams, although the heavy textured soils are potentially higher yielding.

Soybean forms nodules on its roots which contain *Rhizobium* bacteria. These bacteria fix nitrogen in the roots which the soybean plant can use for growth. The *Rhizobium* inoculum is required by non- promiscuous varieties- varieties that which cannot nodulate on their own. The promiscuous soybean varieties can nodulate naturally or can fix nitrogen on a wide range of soil types (MACO, 2002). For fields with no history of soybean production, inoculation is required for optimal production (Mutegi and Zingone, 2012). If soybean are not grown in association with *Rhizobium*, they will grow more slowly, require nitrogen fertilizer, and yield less but the *Rhizobium* inoculum must be fresh (Martin, 1998).

Nitrogen fixation influences soybean yields significantly (Martin, 1998). The nitrogen requirement of a soybean crop is estimated at 350 kg N ha<sup>-1</sup>. With adequate supply of P, soybean can fix up to 450 kg N ha<sup>-1</sup> making it possible for the crop to satisfy its nutritional requirements and leave some residual N for use by associated crops. The amount of fixed nitrogen which is ultimately used by soybean crop is a function of available N, with the plants utilizing available soil N prior to fixed N. Application of N to a soybean crop that is already fixing N may, therefore not improve soybean yields (Mutegi and Zingone, 2012). Soybean are very salt sensitive (about twice as sensitive as maize). If fields have not been under soybean in the last four years or the field has been flooded, seed should be inoculated with *Rhizobium japonicum* bacteria (Mc Williams, 1999). The soybean crop can get enough moisture under rain fed conditions. However, as with all crops requiring supplementary irrigation in a rainfall season due to situations of poor rainfall distribution, soya requires about 450-800mm of water, but in a short growing period. The stages that are critical or very sensitive to moisture stress are flowering and pod filling (Moono, 1995).

## **2.4 Plant Development**

Development of soybean, indeterminate and determinate types, undergoes two main stages. The vegetative (V) stage takes about 40 days while the reproductive (R) stage occurs within about 45 days as shown in (Table 1). Management practices that

may influence crop development include seedbed preparation, variety selection, planting rate, planting depth, row width, pest management (diseases, insects and weeds), and fertilization and harvesting (Mc Williams, 1999).

Root growth begins at germination while primary and lateral roots grow strong until R5. After R5, the shallower roots degenerate, but the deeper roots and laterals grow until R6.5. Nodulation occurs as early as V1 and continues through the V stages. Nitrogen is fixed by the *Rhizobium* and is fed to the plant. Phosphorus and potassium are taken up by the roots-slowly at first, then rapidly. Rapid nutrient uptake occurs before a period of rapid growth (K. State, 1997).

The reproductive stages are divided into 4 parts: R1 and R2 describe flowering; R3 and R4 describe pod development; R5 and R6 describe seed development; and R7 and R8 describe plant maturation (Mc Williams, 1999). Most nutrients are taken up by the time the plant reaches R6 stage. Stage R4 marks the beginning of the most crucial period of plant development in terms of yield determination. Stress (moisture, high temperature, nutrient deficiencies, lodging, or hail) occurring from R4 to R6.5 will reduce yields more than the same stress at any other period of development. Stages R4.5 through R5.5 are especially critical. Young pods are more prone to abort under stress than older pods and seeds. Stresses at this stage can greatly affect final performance (K. State, 1997).

**Table 1:** General vegetative and reproductive development stages in soybean (*Glycine max*)

Stage	General description	Days from planting
<b>Vegetative Stage</b>		
VE	Hypocotyl emergence above ground.	5-10
VC	Unifoliolate leaves fully expanded	15
V1	Full expansion of first trifoliolate	20
V2	Plant has three nodes, 14-19 cm tall and having 2 unfolded trifoliolates. Nodulation and active N-fixation starts.	25
V3	Four nodes with 3 unfolded trifoliolates and plant at 17-22 cm tall.	29
V5	Six nodes with 5 unfolded. Increased branching occurs.	35
V6	Seven nodes, with 6 unfolded. Unifoliolate and cotyledons senesced. Plant at 29 cm tall.	40
<b>Reproductive Stages</b>		
R1 (V7-V10)	Beginning bloom. At least one flower located on the plant at any node on the main stem.	50
R2 (V8-V12)	Full bloom. An open flower at the top two nodes of the main stem.	55
R3	Beginning of podding. A pod on the upper four nodes is 3/16 inch (0.5 cm). Crucial stage for seed yield.	60
R4	Full Pod. Rapid pod growth and beginning of seed development 3/4 inch (2.0 cm) long.	65
R5	Beginning seed. Much water needed. Peak of N-fixation.	70
R6	Full seed also called "Green Bean" stage. Rapid growth rate. Root growth ceases at R6.5.	75
R7	Beginning maturity. One normal pod on the main stem obtains mature colour (brown or tan). Dry matter begins to peak in individual seeds.	85
R8	Full maturity, 5 % of the pods have reached their mature colour and only 5-10 days of good drying weather after this stage is required to have the soybean at less than 15 % moisture or harvest moisture.	95

Modified from Mc Williams, 1999 and KSTATE, 1997

## **2.5 Threats and challenges to production**

The challenges growers face in crop production, include unpredictable weather, diseases, pests, weeds and variable soil quality. Soybean is affected by all of these variables. Some strategies for increasing yields include the use of fertilizers and pesticides, while others involve developing new plant varieties that best suit the needs of the farmers. In soybean, localized variety development is important so that growers use varieties that are well adapted to local conditions such as weather, preferred agronomic practices and photoperiod. However, increases in crop production due to varietal improvements are often offset by constraints caused by broadly categorized abiotic and/or biotic factors (Hartman et al., 2011). Key strategies for improving soybean yields include; adoption of high yielding varieties, soil fertility management, pest/disease control, observing the most appropriate planting time and planting density (Hartman et al., 2011). Crop productivity is determined by a number of parameters including plant spacing. Row spacing and plant population recommendations may vary for each location. Seed yield increases with decreasing row spacing, up to a point, and declines when plant density is further increased (Mehmet, 2008). Plant population is a production factor which affects light interception by the plant canopy (Board, 2000).

### **2.5.1 Common biotic stresses associated with soybeans**

Biotic constraints, such as pathogens, pests and weeds, are detrimental to soybean production and result in significant negative impacts on yield. Pathogens and pests of soybean infect and/or attack all parts of the plants from roots to seeds. The extent of economic plant damage depends upon the type of pathogen/pest, plant tissue being attacked, and number of plants affected, severity of attack, environmental conditions, host plant susceptibility, plant stress level, and stage of plant development (Hartman et al., 2011).

Although pests are not yet a serious problem to soybean seed production in Zambia some pests have the potential to reduce both yield and quality of the grain (Miti, 1995). According to (MACO, 2002), soybean can withstand up to 20 to 30 % of foliage loss before flowering without serious yield losses. However, occasionally the

crop is attacked by cutworms (*Agrotis* spp.), loopers and caterpillars (*Chrysodeixis includes*), and stink bugs (*Halyomorpha halys*). Termite (*Isoptera*) damage is prevalent when there is a dry spell (Miti, 1995).

Nematodes are also known to attack soybean. Many species of nematodes feed on the soybean but the two forms that are the most damaging are the soybean cyst nematode (*Heterodera glycines ichinohe*) and the root knot nematode (*Meloidogyne* spp.) Symptoms of nematode damage are stunting, wilting under moisture or temperature stress, and reduced yields (Sleper and Poehlman, 2006).

Soybean is attacked by a wide range of diseases, most of them seed borne (Neergaard, 1979). The most common soybean diseases in Zambia are:-Red leaf blotch (*Pyrenochaeta glycines*), bacterial blight (*Pseudomonas glycines*), bacterial pustule (*Xanthomonas glycines*), Downy mildew (*Peronospora manshurica*), Purple seed stain (*Cercospora kikuchii*) and frogeye leaf spot (*Cercospora sojina*).

Economically, the most important disease is red leaf blotch (*Phoma glycinicola/Pyrenochaeta glycines*) and no varietal resistance is yet known for this disease (Miti, 1995; Hartman, 2011). The fungus appears not to be seed borne, but may be transported along with soil and other debris in grain. Yield losses of up to 50 % were documented in Zambia and Zimbabwe in the 1980s due to red leaf blotch disease (*Pyrenochaeta glycines*) (Hartman et al., 2011). Use of some fungicides (such as those containing both *silicone triazole* and *benzimidazole, flusilazole*, and *triphenyltin hydroxide*) have been shown to suppress the disease (MACO, 2007).

Weeds growing with soybean compete with the crop for light, moisture, and nutrients. Uncontrolled weeds reduce soybean yields and interfere with harvest. An effective weed-management program requires knowledge of the impact of weeds and implementing a timely weed-control program. Soybean is very competitive with weeds once the soybean reach full canopy, but early emerging weeds can cause serious problems. Thus, early-season weed control (first 7 weeks or up to R1) is the key to providing the soybean with a competitive advantage and minimizing the effect of weeds. The most effective weed-control programs involve a variety of control practices in an integrated weed-management system, including crop rotation,

cultivation, sound agronomic practices, and judicious use of herbicides (Thoenes, 1997; MACO, 2002).

## **2.6 Vegetative plasticity**

Vegetative plasticity is how the extent to which individuals reduce their leaf area and vegetative dry mass strongly influences yield when total plant mass is reduced by adverse conditions or dense stands (Squire, 1990). The same author suggested that the reciprocal of leaf area or dry mass per plant increases linearly with population over a wide range so that the response can be described by an intercept and a slope (Squire, 1990).

Phenotypic plasticity has been observed in soybean crop communities in response to seeding rate (Carpenter and Board, 1997; Board, 2000), and row spacing (Mellendorf, 2011). Soybean has the ability to make adjustments to available space which allows the communities to achieve optimum yields over a broad range of plant arrangements. However, the mechanism responsible for this yield compensation is not fully understood (Egli, 1988; Carpenter and Board, 1997). Plants exhibit great morphological plasticity in their response to the environment such as the number of neighbouring plants (i.e. population density). Plant height, for instance, increases (relative to biomass, stem diameter and leaf area) as population density increases (Sekimura et al., 2000).

## **2.7 Plant competition**

Plant competition occurs when two or more plants are in demand of common environmental resources in excess of supply. This competition can generally be categorized into two types. Inter-specific competition is one occurring among multiple species and is usually demonstrated as competition between a desired crop and weeds. On the other hand, intra-specific, or interplant competition, is when common resources are limited for all the plants of a similar specie, such as between the established crop plants with a given crop canopy. This leads to individual plant productivity being typically limited by competition for light, water, soil nutrients or a combination of each (Buhler and Hartzler, 2004). As an example regarding plant height, Holmes and Smith, (1977), report that the stem sections of plants that receive

more light usually tend to have slower elongation rates. The level of light, as well as the ratio of red/far red light, plays an important role in stem elongation and, consequently, on final plant height (Park and Runkle, 2017).

### **2.7.1 Plant density and yield development**

Two general concepts are often used to explain the relationship between row spacing, plant density, and crop yield. In the first concept, maximum crop yield can only be achieved if the crop community is able to produce sufficient leaf area to provide maximum light interception during reproductive growth. Second, equidistant plant spacing maximizes yield because it minimizes interplant competition (Mellendorf, 2011; Shamsi and Kobraee, 2011).

Plant density affects the amount of solar radiation interception by the canopy. Therefore, it appears that the biomass production of solar radiation intercepted by the canopy closure and increased interception of photosynthetically Active Radiation (PAR) is needed for carbohydrate production in the plant (McKenzie et al., 1992). Seed yield is determined as the product of biomass (BM) and harvest index (HI). Acknowledging that soybean harvest index is constant in most environments (Mehmet, 2008), maximizing BM should produce the highest yields. This is as was postulated by Duncan (1986), that, the greater the total dry matter (TDM) the greater the yield, as long as the TDM is produced before seed initiation. Furthermore, it has been suggested that optimal crop growth rate (CGR), or dry matter (DM) production, resulted when leaf area index (LAI) is sufficient (3.0-3.5) to achieve near maximum light interception (LI), 95 %, by R5 (Shamsi and Kobraee, 2011).

Alternatively, yield can also be considered a function of four basic factors, commonly called 'yield components', which include seed mass, number of seeds/pod, number of pods/plant, and number of plants per given area. Identifying which yield components contribute the most to yield and yield compensation under given crop management situations would help understand necessary management to achieve optimal yields (Carpenter and Board, 1997).

### **2.7.2 Plant density, assimilate partitioning and genotypic differences**

Partitioning of dry matter between the structures of a plant is influenced by all the main environmental and cultural factors. It is inherently very complex, depending on the source of assimilate produced by the foliage, the different “sinks” for assimilate, as determined by the number and size of sub-units in a structure, and on the capacity for movement of assimilate between source and sink, sometimes by way of a transitory store. Population density has important effects on the attributes controlling partitioning of dry matter. When dry matter is expressed per unit field area, both the total dry matter at harvest, and  $W_0$  (Dry mass of the plant when the structure effectively begins to grow) for most structures, increases with rise in plant population. The attributes of  $W_0$  and  $p$  (The rate of dry matter partitioning) sometimes differ consistently between genotypes (Squire, 1990). In soybeans, Egli (1988) found that indeterminate cultivars increased seed yield linearly up to a higher population density almost twice that of determinate genotypes. The type of photosynthetic pathways (C3 or C4) also affect assimilates partitioning (Squire, 1990).

### **2.7.3 Harvest index, respiration and assimilate partitioning**

The harvest index (HI) is used for partitioning yield and is defined as the ratio of seed yield (SY) to the total biomass [vegetative mass (VM) + SY] at maturity.

$$HI = SY (VM + SY)^{-1}$$

In soybean, experiments showed that shortening the vegetative growth phase and reducing vegetative mass (VM) did not ‘transfer’ biomass to the seeds, there was just less VM produced as HI went up as the cultivars flowered sooner and VM decreased. On the other hand, longer seed filling periods are frequently associated with higher yields in many crops due to longer seed filling duration, (SFD) and resulting in a higher HI, unless there is a proportionate increase in VM. Therefore, environmental modifications may affect vegetative growth, but not yield, causing changes in HI (Egli, 1998).

It has been shown that plant height declines with reduced plant population because stem sections of plants that receive more light usually tend to have slower elongation rates. Increased plant populations decrease number of side branches, pod number per

plant, seed yield per plant, 100 seed weight, and harvest index while seed yield per hectare is increased. Harvest index of smaller plants is less than for larger plants, but these smaller plants have little influence on total crop yield and harvest index (Çalifikan et al., 2007; Mehmet, 2008). According to these authors there are three phases in the response of soybean yield to increased plant population. At very low plant population (1–2 plants/m<sup>2</sup>) there is no interplant competition and yield per plant is maximized (Phase 1). Phase 2 begins as plants compete with one another for needed resources. Phase 3 is characterized by a positive relationship to increased plant population, although marginal yield increases are smaller for each additional plant. This relationship continues for plant populations greater than those required to intercept all (i.e., ≥95 %) of the available photosynthetically active radiation (PAR), indicating that complete interception of PAR does not guarantee attainment of maximum yield. Finally, in Phase 3, soybean yield per unit ground area is maximized, and there are no further increases in soybean yield for increased plant population and this yield does not continue to increase at high population densities (Phase 3) because of the decreased radiation use efficiency (Mehmet, 2008).

## **2.8 Seed quality and effects of plant density**

Seed quality is defined along two broad dimensions: seed quality *per se* and varietal quality, the two being quite distinct with seed quality being additionally affected by storage technology since pests and diseases may also physically damage the seed, impairing germination and reducing plant vigour (Walsh et al., 2014).

Seed quality consists of the health, physiological and physical attributes, such as the absence/presence of disease, whether grains are fully mature, and the absence/presence of inert material such as stones or dust. The physiological condition of a seed, part of seed quality, refers to the state of the embryo and its ability to grow (seed germination). While many seeds are innately dormant after harvest, unable to grow even under favourable conditions, there are several attributes that may influence the number of seeds that will germinate (germination percentage). Superior quality seeds generally lead to more vigorous seedlings, which can produce more flowers (ears of corn or bean pods) and result in higher yields (Walsh et al., 2014; ISTA, 2016).

Variety quality refers to the genetics of seed. It may consist of attributes such as plant type, duration of growth cycle, seed colour and shape. Genetics can determine whether the seed can adapt to local conditions, and often influence farmer and market demand. While some varieties may be affected differently by storage conditions than others, storage conditions will not affect the actual genetic composition of the seed. The standard germination test and vigour test are used to provide information about the planting value of seed in a wide range of environments (Walsh et al., 2014; ISTA, 2016).

Seed vigour is the sum of those properties that determine the activity and performance of seeds of acceptable germination in a wide range of environments; it is not a single measurable property but is a concept describing several characteristics associated with germination uniformity, emergence ability and performance after storage. A vigorous seed lot is one that is able to perform favourably even under conditions which are not optimal for the species using either a direct or indirect analytical procedure. Direct tests reproduce environmental stresses or other conditions in the laboratory and the percentage and /or rate of seedling emergence are recorded while indirect tests measure other characteristics of the seed that have proved to be associated with some aspect of seedling performance (ISTA, 2016).

A study conducted by Shena, et al. (2011), showed that increasing plant population resulted in reduced vigour, but the differences were not significant at any densities. These results differed from those found by Castillo (1992), where in his experiment with garden peas (*Pisum sativum* L.), seeds from a population of 200 plants/m and 10 cm row width harvested at 15 % seed moisture content had lower vigour than less dense plantings, a fact which was attributed to high temperature and relative humidity within the crop canopy.

A germination and vigour test was used in this case to determine if varying plant density had any effect on the planting value of the seed post-harvest in reference to the field conditions during growth where the five soybean varieties were subjected to.

## CHAPTER 3: MATERIALS AND METHODS

### 3.1 Location and planting

The study was conducted at the Seed Control and Certification Institute (SCCI), situated 15° 32.772' S and 28° 15.796' E and elevation of 1,246 m above sea level in Chilanga district of Lusaka Province of Zambia from December 2014 to April, 2015. The site is in agro-ecological region II of Zambia. The length of the growing period for the plants ranged from 117 to 152 days. Some intra-seasonal dry spells were experienced. The land on which the experiment was conducted on was virgin. The soils fall in the Makeni series of Sandy-loams and classified as Ultic Haplustalf (USDA, 1999).

The seeds were dressed with inoculant at the rate of 500 g/ha of *Rhizobium* called NITROZAM (5% (w/v) molasses medium, 0.3 % CaCO<sub>3</sub>, 0.1 % yeast extract) obtained from the Zambia Agriculture Research Institute at Mt. Makulu before being planted. Planting was done by drilling and ensuring that seeds were evenly spaced. Planting was done on the 21<sup>st</sup> of December, 2014 and harvest was done by 22<sup>nd</sup> April, 2015. Normal planting period for soybean in Zambia is middle to end of December; hence planting was done within the recommended period. Upon germination, stands were thinned to maintain the stated plant populations. Basal dressing fertilizer was applied soon after germination at the rate of 20 kg N, 40 kg P<sub>2</sub>O<sub>5</sub> and 20 kg K<sub>2</sub>O (D Compound) per ha following the recommendations (Miti, 1995). Other required agronomical practices for growing soybean were followed.

### 3.2 Analysis of soil chemical properties

Before planting, soil samples were collected from a depth of 0-30 cm and submitted for laboratory analysis.

#### *Soil reaction (pH)*

The soil pH was measured using the electrometric method (Schofield and Taylor, 1955).

#### *Soil organic carbon*

The Walkley-Black (1934) wet digestion method for determining organic carbon was used.

#### *Total soil nitrogen*

The soil Total N was measured using the Kjeldahl method according to Bremner (1965).

#### *Available phosphorus*

Analysis of available Phosphorus was done according to the method by Bray and Kurtz (1945).

#### *Exchangeable bases*

Exchangeable bases were determined by use of the ammonium acetate method (Toth and Prince, 1949).

#### *Plant materials*

Five soybean genotypes were planted in the field. The varieties (Table 2) were obtained from seed companies. Selection of the genotypes was based on their being popular with the farming community and differences in growth habit (determinant and indeterminate). All the materials were officially released varieties and available on the Zambian market. The varieties also belonged to different maturity groups. Among the genotypes used, only Magoye was promiscuous in its nodulation. Promiscuity is the ability to form root nodules and be able to fix atmospheric nitrogen without the need for inoculation with Rhizobium.

### **3.3 Data Collection and analytical procedures**

Data were collected on morphological and physiological traits as well as on yield and yield components. Vegetative and reproductive parameters were collected during the different development phases of the crop. The parameters collected were plant height (PH), number of branches (NB), chlorophyll content at V4 (Chl T1), chlorophyll content at V6 (Chl T2), nitrogen content (NC), days to 50% flower (50%DF), days to pod filling (DPF), days to maturity (DM), biomass yield at R3

**Table 2:** Soybean (*Glycine max*) materials used in the experimental trial

<b>Variety</b>	<b>Growth Type</b>	<b>Nodulation</b>	<b>Origin</b>	<b>Year of release</b>
SC Safari	Determinant	Non promiscuous	SeedCo International (Z) Ltd	2004
Dina	Determinate	Non promiscuous	Maize Research Institute	2003
Magoye	Determinant	Promiscuous	Zambia Seed Company Ltd	1981
Kaleya	Indeterminate	Non promiscuous	Zambia Seed Company Ltd	1981
Pan 1867	Indeterminate	Non promiscuous	Pannar Seeds (Z) Ltd	2010

Source: SCCI 2013 Variety Register

**Table 3:** General characteristics of the five test Soybean (*Glycine max* L.) varieties

<b>Characteristic</b>	<b>SC Safari</b>	<b>Dina</b>	<b>Magoye</b>	<b>Kaleya</b>	<b>Pan 1867</b>
<b>Plant</b>					
Growth Habit:	Erect	Erect	Semi Erect	Semi Erect	Semi Erect
Growth Type:	Determinate	Determinate	Determinate	Indeterminate	Indeterminate
Plant Height:	Medium to short	Tall	Tall to Very tall	Tall	Medium to short
Hairiness:	Medium	Medium	Medium	Medium	Medium
Colour of hairs:	Brown	Brown	Brown	Brown	Grey
<b>Leaves</b>					
Shape of leaflet:	Lanceolate to Rhomboidal	Rhomboidal	Elliptic	Elliptic	Ovoid
Leaf colour:	Light Green	Green	Green	Dark Green	Medium green
<b>Flower</b>					
Time to 50% flowering:	Early	Late	Medium to Late	Medium to Late	Early
Colour:	Violet	Violet	Violet	Violet	Violet
<b>Pod</b>					
Colour at Maturity:	Medium Brown	Brown	Medium Brown	Light Brown	Dark brown
<b>Kernel</b>					
Shape:	Spherical	Spherical	Elongated flattened	Spherical flattened	Spherical
Colour of Hilum:	Brown	Black	Dark brown	Medium Brown	Grey
Colour of Testa:	Yellow	Green Yellow	Yellow	Yellow	Yellow
<b>Agricultural characteristics</b>					

Maturity:	Medium early	Late	Very Late	Medium to Late	Medium early
Yield:	Low	High	Very High	Very High	Low
Shattering					
Resistance:	Strong	Very Strong	Medium to Weak	Very Strong	Medium to Weak
Lodging resistance:	Strong	Strong	Strong	Strong	
<b>Disease Resistance</b>					
Leaf diseases	Strong	Susceptible to Rosette	Strong	Strong	Susceptible to <i>Cercospora kikuchii</i> (Purple blotch)
<b>Adaptation</b>					
Region of adaptation:	Adapted to medium rainfall conditions	Adapted to high rainfall conditions	Adapted to high rainfall areas due to its late maturity	Adapted to both high and low rainfall conditions	Adapted to high rainfall conditions.
<b>Farming System:</b>	Needs seed inoculation	Needs seed inoculation	Magoye has the ability to nodulate without seed inoculation. It is suitable for both large and small scale farmers.	Needs seed inoculation	Large grain size Needs seed inoculation. High management care
<b>General:</b>		(General: At maturity many leaves remain attached to the plant)	(General: At maturity many leaves remain attached to the plant)		

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Adapted from A Descriptive List of cultivars-soybean (2011) Seed Control and Certification Institute

growth stage (BM 1), biomass yield at harvest (BM 2), pods per plant (NPD), number of seeds per plant (NSD), one hundred seed weight (100 SW), yield (Yd), seed vigour (SV) and germination at post-harvest

### **3.3.1 Vegetative parameters**

#### *Plant height and number of branches*

Plant height was measured with a ruler at R6 - R7 growth stage. This is because at this point the plant will have attained its full height and root growth had ceased. Delaying to collect plant height data could lead to obtaining inaccurate results because of possible lodging and leaf fall associated with senescence (McWilliams, 1999; Casteel, 2011). The number of branches was measured by counting five plants at random and averaging the result at between R6 and R7 stage. The number of branches has a bearing on final yield obtained as pods tend to be borne on the branches.

#### *Days to 50 % flowering, days to pod filling and days to full maturity*

The days to 50 % flowering occurs at the time a plant begins its reproductive growth phase. At this stage, about 50 % of flowers are fully open (UPOV, 1998). The number of days was calculated from the time of plant emergence to when the plants reached 50 % flowering and data was collected at the R1-R2 growth stage.

Full seed occurs at R6 growth stage and this stage is also known as the “green bean stage” (McWilliams et al., 1999). The total number of days from emergence to this stage was calculated as the days to pod filling.

Full maturity occurred at the R8 growth stage (McWilliams et al., 1999; Casteel, 2011). The number of days was thus calculated from emergence to R8. This was the plant’s whole growth period and determined varietal maturity differences and effects of plant density.

#### *Biomass yield at R3 and at harvest*

Biomass was determined by sampling 5 plants per replication at the R3 growth stage and drying them at 65 °C for 48 hours (Peoples et al, 1989) before weighing them.

This was done to compare the weights of the three population densities. The biomass weight at harvest was obtained by sampling five plants at harvest time (R8) per replication and weighing them. At this stage, most roots had senesced and could not be harvested as part of total biomass so the canopy biomass instead was what was determined. The biomass weight at harvest was expressed as kg/m<sup>2</sup>.

#### *Chlorophyll content and nitrogen content*

Chlorophyll content (between V4 and V6) was obtained by use of Chlorophyll meter (Konica Minolta Spad 502 Plus). SPAD chlorophyll meter reading (SCMR) is a quick, non-destructive measurement of the chlorophyll content of plant leaves (Moe, 2012). Nitrogen content assessment was done at the R3 growth stage when nitrogen fixation and nodulation are expected to be occurring (Peoples et al, 1989) before laboratory analysis for nitrogen content using the micro Kjeldahl (Bremner, 1982).

### **3.3.2 Reproductive parameters**

#### *Number of pods per plant and number of seeds per plant*

The number of pods per plant was determined by counting pods of five sampled plants and finding the mean number of pods per plant. This was done at the R7-R8 growth stage when all the pods had fully formed and matured. The number of pods per plant is a significant factor in determining the plant yield (Casteel, 2011). The number of seed per plant was calculated by multiplying averages of locules per pod and pods per plant. Like the number of pods per plant, the number of seeds per plant contributes to the determination of the final yield (Casteel, 2011).

#### *Hundred Seed weight and yield*

Seed weights were obtained by counting 100 seeds in three replicates, weighing them and obtaining an average to come up with an accurate 100 seed weight in grams. Yield was then calculated as a function of the base population, pod number per plant, seeds per pod and seed weight (Casteel, 2011) at the harvestable moisture content of 15 % and measured in tons/ha.

### **3.3.3 Seed quality**

#### *Post-harvest germination and vigour*

Post-harvest germination was conducted on all varieties from the three plant densities to check on effect of density stress. Germination test was conducted following ISTA methods of determining germination (ISTA, 2016). A hundred seeds were tested and sand was used as the medium in pots in controlled environment. Determination of the results was done after 8 days from planting. Vigour was determined at 5 days as recommended by ISTA (2016). This test was conducted to check the effect of plant density in the field during whole plant growth. Both germination and vigour results are determined in percentage (%).

### **3.4 Design and Data Analysis**

The trial was laid out in a randomised complete design (RCBD) and analysed as a two way factorial with treatments replicated four times (Gomez and Gomez, 1984). The two main factors were the variety (five varieties) and plant density (three densities). The whole field measured 18.5 x 11 m long. The subplots measured 2 x 0.5 m long and had 2 rows. The genotypes Kaleya, Magoye, Pan 1869, Sc Safari and Dina were the varieties assigned to main plots and plant densities were assigned to the subplots. The three plant population densities used were 300,000 plants/ha (D1), 400,000 plants/ha (D2) and 550,000 plants/ha (D3). The 400,000 plants/ha is the recommended plant population in Zambia (Miti, 1995). Data was analyzed using the statistical package GenStat Version 12. Data were subjected to an analysis of variance (ANOVA) in order to determine significant differences among treatments for various parameters at 95 % level. Mean separation was done using the least significant difference (LSD) and Bonferroni test for multiple comparisons while Pearson's simple correlation was used.

## **CHAPTER 4: RESULTS**

### **4.1 Soil chemical properties**

The results on the chemical properties of the soil at the experimental site are presented in Table 4. The soil reaction (pH) was 6.4 which was slightly acidic but supports normal crop growth and did not need liming. The soil indicates moderate soil fertility status with organic carbon and total nitrogen content of 0.56 % and 0.03 %, respectively. However, the soil had low phosphorus and moderate potassium content and Cation exchange capacity (CEC). The soil was classified as sandy-loam Ultic Haplustalf (USDA, 1999).

### **4.2 Effects of variety and population density on morpho-physiological traits**

The morphological and physiological responses of soybean genotype showed significant differences among the five varieties (Table 5). The population density had significant effect on the number of branches per plant, biomass yield at R3 growth stage, biomass yield at harvest, number of pods per plant, number of seeds per pod and yield. Significant interactions between genotype and population density for number of pods per plant and number of seeds per pod only were observed.

### **4.3 Effect of genotype and plant population density on number of branches per plant**

Table 6 shows the effect of genotype and plant density on branching. Both the genotype and density exerted significant effects ( $P < 0.001$ ). The interaction of these two factors was not significant. The highest number of branches were recorded from genotype Kaleya (5 branches/plant) followed by Pan 1867 (4 branches/plant) while the least number of branches per plant was recorded from Dina (3 branches/plant). Increasing the plant population density from the optimal density of D2 (4 branches/plant) to D3 (3 branches/plant) resulted in reduction in the number of branches per plant. The number of branches per plant reduced as plant population increased from D1 to D3.

**Table 4:** Soil chemical profile of the experimental site located at the Seed Control and Certification Institute

<b>Soil parameter</b>	<b>Analysed Soil</b>	<b>Soil Critical Values</b>	<b>Soil status</b>
pH (CaCl <sub>2</sub> )	6.4	4.5	Slightly acid
Organic C (%)	0.56	1.58	Low
N (%)	0.03	0.1	Very low
Exchangeable Bases Concentrations (cmol/kg soil)			
P <sup>3-</sup>	0.129	0.484	Low
K <sup>+</sup>	2.483	1.024	Moderate
Ca <sup>2+</sup>	70	10	High
Mg <sup>2+</sup>	39.984	4.165	High
Na <sup>+</sup>	2.391	–	High
CEC	16.3	–	Moderate

**Table 5:** Summary of ANOVA of treatment effects on 5 genotypes of soybeans (*Glycine max*) subjected to three levels of plant densities

Source of variation	D.F.	PH	NB	Chl T1	Chl T2	NC	50% DF	DPF	DFM	BM <sub>1</sub>	BM <sub>2</sub>	NPD	NSD	SW	Yd	G	SV	
Rep stratum	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rep.*Units* stratum																		
Variety	4	**	**	**	**	*	*	**	**	**	*	**	**	**	**	**	**	**
Density	2	ns	**	ns	ns	ns	ns	ns	ns	**	**	**	**	ns	*	ns	ns	
Density x Variety	8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	
Residual	42																	
Total	59																	
CV %		4.4	4.3	2.8	2.4	17.2	0.1	0.1	6.7	8.8	8.5	11.2	11.3	3.0	13.7	3.6	3.5	

Level of significance: ns : non- significant, \* : significant at P = 0.05, \*\*: significant at P ≤ 0.001.

**Table 6:** Main effects of variety and plant density on plant height and number of branches per plant of soybean (*Glycine max*).

Treatment	Plant height (cm)	Number of branches per plant
Variety		
Sc Safari	49.8 a	3.8 b
Dina	76.6 c	2.983 a
Magoye	77.7 c	3.367 ab
Kaleya	62 b	5.35 c
Pan 1867	48.3 a	4.067 b
Density		
D1	62.2 a	4.3 b
D2	62.9 a	4.18 b
D3	63.5 a	3.26 a
Factor Effects		
Variety	<0.001	<0.001
Density	0.928	<0.001
Variety * Density	0.991	0.218

#### **4.4 Effect of genotype and plant population density on chlorophyll content**

The results for chlorophyll content at V4 and V6 growth stages are presented in Table 7. Leaf chlorophyll content effects at V4 growth stage among the varieties were significant and partly influenced by growth habit, but the main effect of planting density did not exert significant effects. The interaction of these two factors was non-significant. SC Safari had the most chlorophyll content (33.7 nmol/cm<sup>2</sup>) followed by Pan 1867 (33.1 nmol/cm<sup>2</sup>) while Magoye (28 nmol/cm<sup>2</sup>) had the least chlorophyll content. A similar trend was exhibited at V6 growth stage where SC Safari had the most chlorophyll content (36.9 nmol/cm<sup>2</sup>) followed by Pan 1867 (35.4 nmol/cm<sup>2</sup>) while Magoye (31.7 nmol/cm<sup>2</sup>) had the least chlorophyll content.

#### **4.5 Effect of genotype and plant population on nitrogen content**

Results of nitrogen content are shown in Table 7. The effect of variety was significant ( $P=0.017$ ) but the effects of plant density and the interaction between the variety and plant density was not. Kaleya variety accumulated the most nitrogen (2.53 % N) overall followed by SC Safari (2.33 % N) while Dina (1.52 % N) accumulated the least amount of nitrogen. The average nitrogen content among the densities was 2.069 % N.

#### **4.6 Effect of plant population density and genotype on days to 50 % flowering, days to pod filling and days to full maturity**

Table 8 shows the influence of genotype and population density on vegetative phase change to maturity. The effect of variety on days to 50 % flowering was significant ( $P<0.001$ ), but not plant density. The interaction of these two factors was also not significant. The variety Dina had the highest number of days to 50 % flowering (67 days) followed by Magoye (65 days) and the least was Pan 1867 (47 days) respectively. On the number of days to pod filling (Table 8), the main effect of variety was highly significant ( $P<0.001$ ), but the main effect of plant density was non-significant. The interaction of these two factors was also non-significant. Dina

**Table 7:** Main effects of variety and plant density on chlorophyll content at V4 and V6 and Nitrogen content of soybean (*Glycine max*)

Treatment	Chlorophyll content at V4 (nmol/cm <sup>2</sup> )	Chlorophyll content at V6 (nmol/cm <sup>2</sup> )	Nitrogen content (%)
<b>Variety</b>			
Sc Safari	33.71 b	36.94 a	2.329 ab
Dina	30.71 ab	34.51 b	1.521 a
Magoye	28.41 a	31.69 a	2.113 ab
Kaleya	31.4 ab	35 b	2.534 b
Pan 1867	33.07 b	35.4 b	1.846 ab
<b>Density</b>			
D1	31.7 a	34.78 a	2.195 a
D2	31.54 a	34.65 a	2.266 a
D3	31.14 a	34.68 a	1.746 a
<b>Factor Effects</b>			
	<b>P-values</b>		
Variety	<0.001	<0.001	0.017
Density	0.782	0.98	0.071
Variety * Density	0.937	0.545	0.256

**Table 8:** The main effect of variety and plant density on days to 50 % flower, days to pod filling and days to maturity of soybeans (*Glycine max*).

Treatment	Days to 50% flower	Days to pod filling	Days to maturity
Variety			
Sc Safari	51.917 b	68.083 a	120.1 a
Dina	66.833 e	85.167 e	151.8 ab
Magoye	64.667 d	77.333 d	164.5 b
Kaleya	56.917 c	75.083 c	131.8 ab
Pan 1867	46.75 a	70.25 b	117.1 a
Density			
D1	57.3 a	75.3 a	146.7 a
D2	57.45 a	75.15 a	132.7 a
D3	57.5 a	75.1 a	131.8 a
Factor Effects		P-values	
Variety	<0.001	<0.001	0.006
Density	0.280	0.280	0.327
Variety * Density	0.808	0.808	0.459

variety took the longest (85 days) to pod followed by Magoye (77 days) with the variety SC Safari (68 days) taking the least number of days to pod. Lowering the plant population density from the optimal of D2 to a lower of D1 or increasing to a higher of D3 did not show any significant differences among the three plant population densities used. Regarding the days to maturity (Table 8), the effect of variety was highly significant ( $P=0.006$ ), but not for density and interaction. Magoye was the latest variety to mature (165 days) followed by Dina (152 days) while the earliest variety to mature was pan 1867. No significant differences were observed among Dina, Magoye and Kaleya but these were different from Dina and Pan 1867 which were the earliest to reach maturity.

#### **4.7 Effect of genotype and plant density on biomass yield and biomass canopy yield at harvest**

The results for biomass yield are presented in Table 9. The results show that the main effect of variety on biomass yield at both R3 and at R8 growth stages was significant ( $P<0.001$  and  $P=0.018$ ), respectively as was the main effect of plant density ( $P<0.001$ ) at both growth stages, while the interaction of the two factors was non-significant. The variety Dina had the highest biomass ( $23.95 \text{ kg/m}^2$ ) at R3 growth stage followed by Magoye ( $18.67 \text{ kg/m}^2$ ) while SC Safari ( $7.23 \text{ kg/m}^2$ ) had the least biomass. The effect of plant density for biomass yield at both R3 and R8 growth stages was significant. Increasing plant density from D1 to D3 resulted into increased biomass at both R3 and R8.

At R8 growth stage, variety Kaleya ( $23.96 \text{ kg/m}^2$ ) and Magoye ( $23.11 \text{ kg/m}^2$ ) were not different. Dina and Magoye were also not different while variety SC Safari ( $16.25 \text{ kg/m}^2$ ), Dina ( $18.46 \text{ kg/m}^2$ ) and Pan 1867( $17.42 \text{ kg/m}^2$ ) did showed significant differences. The results showed a strong positive increasing trend in the amount of biomass with the rise in population density from D1 to D3 at both growth stages ( $R^2 = 0.975$  at R3 and  $R^2 = 0.982$  at R8), respectively. Table 10 presents the effect of variety and planting density on number of pods per plant.

**Table 9:** Effects of varieties and plant density on biomass yield at R3 and at harvest stages soybean (*Glycine max*).

Treatment	Biomass at R3	Biomass at harvest
Variety		
Sc Safari	7.23 a	16.25 a
Dina	23.95 c	18.46 ab
Magoye	18.67 bc	23.11 bc
Kaleya	14.21 ab	23.96 c
Pan 1867	10.98 ab	17.42 a
Density		
D1	10.67 a	10.4 a
D2	14.12 a	18.24 b
D3	20.24 b	30.88 c
Factor Effects		
	P-values	
Variety	<0.001	0.018
Density	<0.001	<0.001
Variety * Density	0.833	0.466

**Table 10:** Main effects of varieties and plant density on number of pods per plant , number of seeds, hundred seed weight and yield of soybean (*Glycine max*).

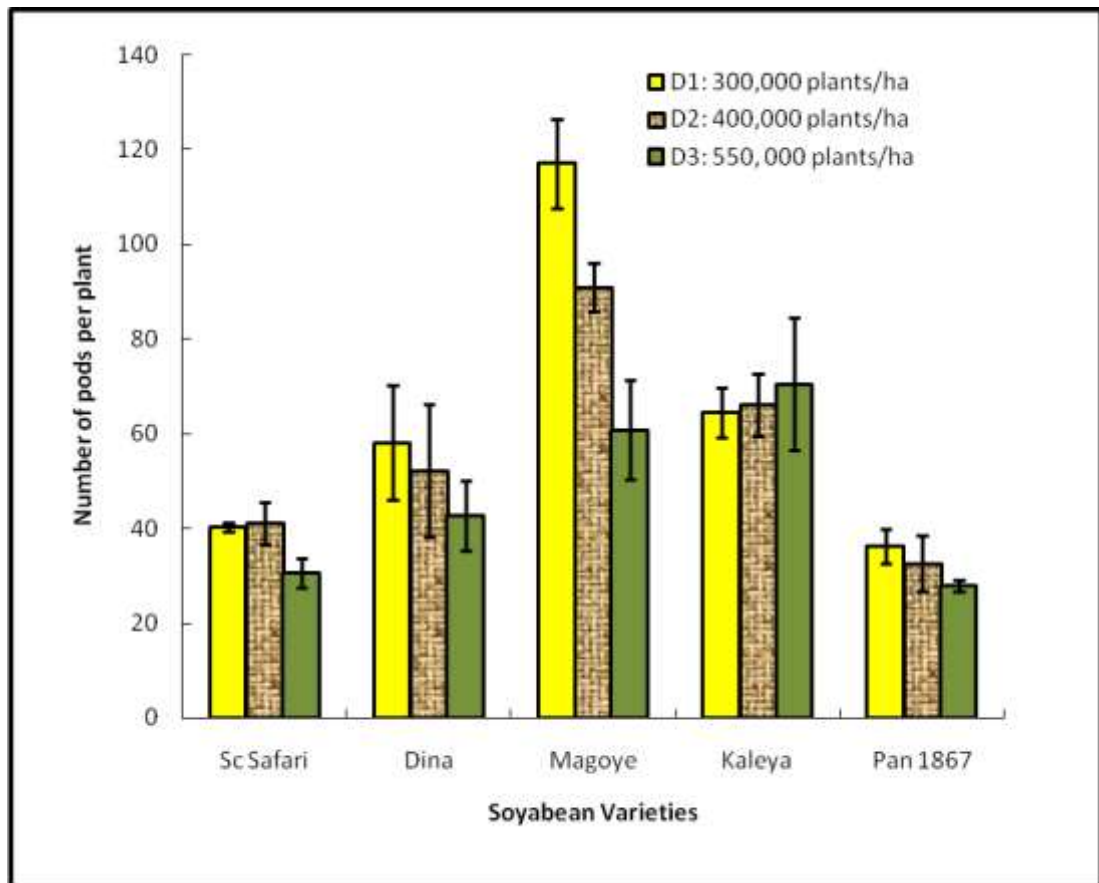
Treatment	Number of pods/plant	Number of seeds/plant	100 Seed Weight (g)	Yield (ton/ha)
Variety				
Sc Safari	19.15 a	37.3 a	14.08 b	1.99 a
Dina	22.5 a	51 ab	14.97 b	2.93 ab
Magoye	40.72 c	89.6 c	11.04 a	3.64 b
Kaleya	30.88 b	67 b	11.68 a	3.08 ab
Pan 1867	18.18 a	32.3 a	18 c	2.18 a
Density				
D1	29.6 b	63.2 b	14.17 a	2.29 a
D2	26.94 ab	56.6 ab	13.89 a	2.81 ab
D3	22.32 a	46.5 a	13.8 a	3.19 b
Factor Effects		P-values		
Variety	<0.001	<0.001	<0.001	<0.001
Density	0.004	0.005	0.474	0.018
Variety * Density	0.016	0.032	0.618	0.433

The main effect of variety ( $P < 0.001$ ) and planting density were highly significant ( $P = 0.004$ ). The interaction of these two factors was also significant ( $P = 0.016$ ) as indicated in Figure 1. Significant differences were observed in the mean number of pods per plant between genotypes Magoye (41 pods/plant) and Kaleya (31 pods/plant) and the rest of the genotypes. However, there were non-significant differences among genotypes SC Safari, Dina and Pan 1867. The highest number of pods per plant were in Magoye (41 pods/plant) followed by Kaleya (31 pods/plant) and the least was Pan 1867 (18 pods/plant). The highest number of pods was in D1 which showed significance with D3 but the difference was non-significant between D1 and D2 and between D2 and D3. Interaction effects were seen in Sc Safari, Magoye and Pan 1867 but not for Dina and Kaleya.

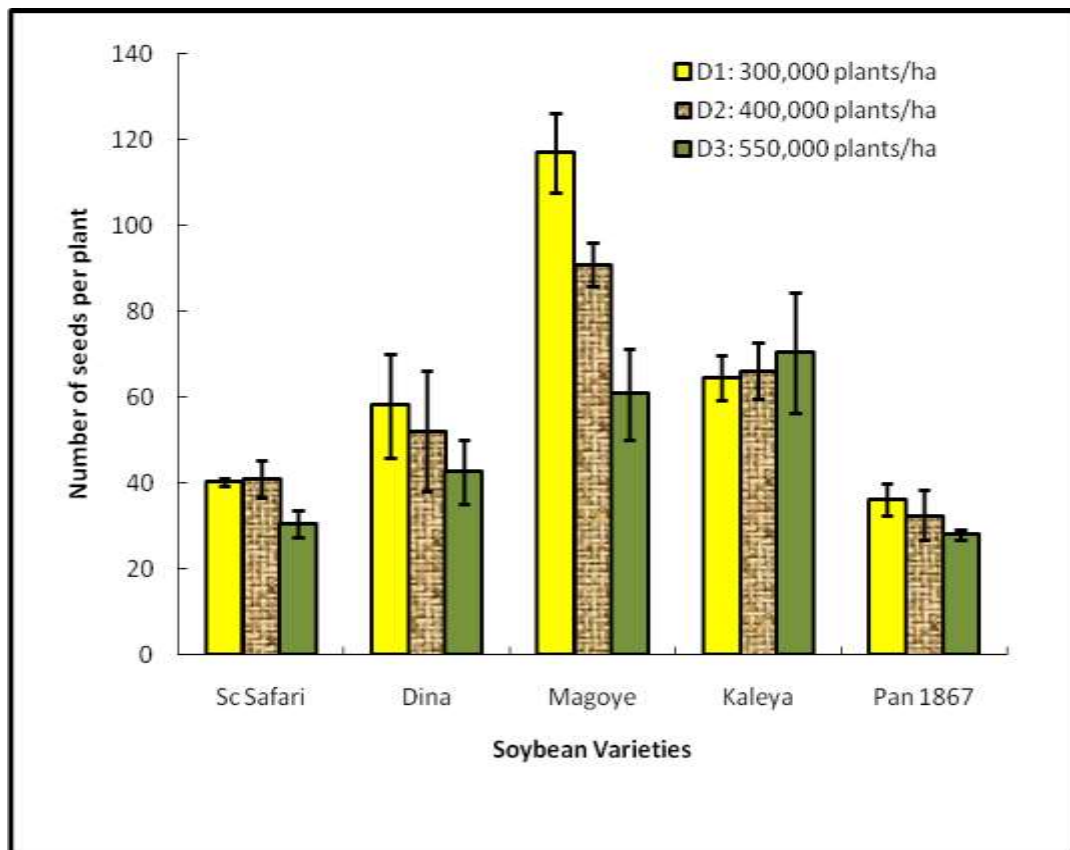
#### **4.8 Effect of genotype and plant population density on seed yield per plant**

The effect of soybean (*Glycine max*) variety and population density on the number of seed per plant are shown in Table 10. The results show that the main effect of variety ( $P < 0.001$ ) and the effect of planting density ( $P = 0.005$ ) exerted significant effects. The interaction of these two factors was also significant as shown in Figure 2. Significant differences were observed in the overall density means for seeds per plant for variety Magoye (90 seeds/plant), and the other four varieties, while non-significant differences were observed between Dina and Kaleya (51 and 67 seeds/plant), respectively. However, non-significant differences were observed between SC Safari (37 seeds/plant) and Pan 1867 (32 seeds/plant).

The density with the most number of seeds per plant was D1 followed by D2 and D3. Significant differences occurred between D1 (63 seed/plant) and D3 (47 seeds/plant). However, there was non-significant difference between D1 and D2 (57 seeds/plant) and between D2 and D3. The interaction effects were present in Sc Safari, Magoye and Pan 1867 but not among Dina and Kaleya genotypes as indicated in Figure 2.



**Figure 1:** Interaction effect of soybean (*Glycine max*) variety and population density on number of pods per plant. Bars indicate standard errors of means.



**Figure 2:** Interaction effect of soybean (*Glycine max*) variety and population density on number of seeds per plant. Bars indicate standard errors of means.

#### **4.8.1 Effect of plant population density and genotype on 100 seed weight**

Response of plants subjected to different plant densities are shown on Table 10. The main effect of variety for 100 seed weight was highly significant ( $P < 0.001$ ), but the effect of plant density was not while the interaction of these two factors was also non-significant. The highest seed weights obtained were from variety Pan 1867 (18.0 g) followed by Dina (14.97 g) and the least was Magoye (11.04 g). The grand mean 100 seed weight was 13.95 g.

#### **4.8.2 Effect of genotype and plant population density on yield**

The results obtained for yield are presented in Table 10 and indicate that the main effect of variety was significant ( $P < 0.001$ ), as was the main effect of plant density ( $P = 0.018$ ) but the interaction of these two factors was non-significant. The highest yield was obtained by variety Magoye (3.64 ton/ha) followed by Kaleya (3.08 ton/ha) and the least was SC Safari in D1 (1.99 ton/ha). The highest yield was obtained in D3 (3.19 ton/ha) followed by D2 (2.81 ton/ha) while the least was D1 (2.29 ton/ha). Significant differences between D1 and D3 were observed but there was non-significant difference between D1 and D2 and between D2 and D3.

#### **4.9 Effect of genotype and plant density for post-harvest seed quality**

The results for post-harvest seed quality are presented in Table 11. The results for post-harvest germination test showed that the main effect of variety was highly significant ( $P < 0.001$ ), but the effect of plant density was non-significant while the interaction of these two factors was also non-significant. Variety Kaleya and Dina showed highest mean germination results across all the population densities at 96 and 95% respectively while the lowest germination test result came from Pan 1869 at 77%. There were no significant differences among Sc Safari, Dina, Magoye and Kaleya but among them and Pan 1867.

**Table 11:** Main effects of genotype and plant density on post-harvest seed vigour and germination of soybeans (*Glycine max*)

Treatment	Germination (%)	Vigour (%)
Variety		
Sc Safari	88.67 b	86.5 b
Dina	94.67 b	90.83 b
Magoye	90.67 b	85.42 b
Kaleya	96 b	94.08 b
Pan 1867	77.42 a	72.17 a
Density		
D1	91.2 a	88.1 a
D2	89.5 a	85.45 a
D3	87.75 a	83.85 a
Factor Effects		P-values
Variety	<0.001	<0.001
Density	0.261	0.189
Variety * Density	0.467	0.498

The results of the post-harvest vigour as indicated in Table 11 showed that the main effect of variety was highly significant, ( $P < 0.001$ ), but the main effect of plant density was non-significant and the interaction of the two factors was also non-significant. Variety Kaleya and Dina were most vigorous (94 and 91 %) respectively, followed by Magoye (85 %) while the least vigorous variety was Pan 1867 (72 %).

#### **4.10 Relationship among morpho-physiological traits, grain yield and yield components of five soybean genotypes**

The strength of association for traits measured with yield as well as the inter component correlation amongst the components are here presented (Table 12). The results showed that plant height ( $r = 0.584^*$ ), number of pods per plant ( $r = 0.697^*$ ), number of seed per plant ( $r = 0.733^*$ ) and biomass yield at harvest ( $r = 0.598^*$ ), were positively and significantly correlated respectively while other traits showed little positive and negative correlation. The results recorded in Table 18 also showed a strong positively and significantly inter component correlations between components. Strong positive correlations were observed between plant height and 50 % days to flowering ( $r = 0.792^*$ ), plant height and days to pod filling ( $r = 0.738^*$ ), number of pods and number of seeds ( $r = 0.979^*$ ), number of pods and days to maturity ( $r = 0.538^*$ ), number of seeds and plant height ( $r = 0.591^*$ ). A strong negative correlation was observed between 50 % days to flower and hundred seed weight ( $r = -0.538^*$ ), hundred seed weight and number of pods per plant ( $r = -0.511^*$ ) and hundred seed weight and number of seeds per plant ( $r = -0.550^*$ ). Other correlations not reported were either weak positive or weak negative hence not well correlated.

#### **4.11 Stepwise multiple regression**

The seed yield was used as the dependent variable while the morpho- physiological traits were used as independent variables. Significant and small contribution to total variations was observed among the independent variables in the study. Biomass yield at harvest had a significant influence on grain yield having the highest Wald statistic of 99.99 % (Table 13).

**Table 12:** Results of correlation between yield and each pair of variables for soybean (*Glycine max*)

100SW	-															
50%DF	<b>-0.538*</b>	-														
BM <sub>1</sub>	-0.130	<b>0.562*</b>	-													
NC	-0.166	-0.120	-0.304	-												
NB	-0.077	-0.349	-0.413	0.326	-											
BM <sub>2</sub>	-0.107	0.134	0.424	-0.086	-0.156	-										
Chl T1	0.380	<b>-0.518*</b>	-0.356	0.042	0.145	-0.213	-									
Chl T2	0.301	-0.433	-0.081	-0.092	0.094	-0.101	<b>0.587*</b>	-								
DFM	-0.257	0.452	0.106	0.067	-0.081	-0.076	-0.385	-	0.417	-						
DPF	-0.205	<b>0.885*</b>	<b>0.632*</b>	-0.239	-0.313	0.089	-0.409	-	0.333	0.365	-					
NSD	<b>-0.550*</b>	<b>0.523*</b>	0.095	0.175	0.279	0.109	-0.401	-	0.379	0.490	0.335	-				
NPD	<b>-0.511*</b>	0.438	0.033	0.204	0.316	0.092	-0.401	-	0.384	<b>0.538*</b>	0.247	<b>0.979*</b>	-			
PH	-0.358	<b>0.792*</b>	<b>0.609*</b>	-0.055	-0.265	0.280	-0.336	-	0.180	0.327	<b>0.738*</b>	<b>0.591*</b>	<b>0.529*</b>	-		
Yd	-0.249	0.415	0.330	0.053	0.065	<b>0.598*</b>	-0.276	-	0.242	0.271	0.336	<b>0.733*</b>	<b>0.697*</b>	<b>0.584*</b>	-	
	100SW	50%DF	BM <sub>1</sub>	NC	NB	BM <sub>2</sub>	Chl T1	Chl T2	DFM	DPF	NSD	NPD	PH	Yd		

\* Correlation is significant at  $P \leq 0.05$ .

**Table 13:** Multiple regression of yield on morphological and physiological traits in soybeans (*Glycine max*) subjected to varying population densities

Response variate:	Yd				
Fitted terms:	Constant, 100 SW, BM <sub>2</sub> , NSD, NPD, PH				
Summary of analysis					
Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	5	70.66	14.1311	69.6	<.001
Residual	54	10.96	0.203		
Total	59	81.62	1.3834		
Estimates of parameters					
Parameter	estimate	s.e.	t(54)	t pr.	
Constant	-1.934	0.526	-3.68	<.001	Wald statistic
BM <sub>2</sub>	0.006191	0.000619	10	<.001	99.99
100SW	0.1205	0.0264	4.57	<.001	20.85
NSD	0.054	0.012	4.48	<.001	20.07
NPD	-0.0478	0.0266	-1.8	0.078	3.22
PH	0.00279	0.00513	0.54	0.588	0.3

Percentage variance accounted for 85.3

Standard error of observations is estimated to be 0.451.

Other variables; plant height, number of pod per plant, number of seeds per plant and hundred seed weight showed significant contributions to total variation with an average  $R^2 = 85.3\%$ . Further additions of other variables to the model did not show significant differences, thus not included in the model. The prediction model for yield was generated as follows:

$$Yd = -1.934 + 0.006191 \text{ BM}_2 + 0.1205 \text{ SW} + 0.054 \text{ NSD} - 0.0478 \text{ NPD} + 0.00279 \text{ PH}$$

## CHAPTER 5: DISCUSSION

The effects of density stress, like all other stresses depend on the plant development stage, the type of stress applied and the degree and the duration of the stress (Squire, 1990). In this study, plants were subjected to three levels of population density during the whole growth duration. Subjecting the soybean to different density levels resulted into a wide variation of the responses of the five genotypes to morpho-physiological traits, grain yield and yield components. Marked genotypic variability in traits measured was observed among the different genotypes. Varying plant density showed impact on important morpho-physiological traits and grain yield and yield components in all the genotypes tested.

Plant height showed significant differences among the genotypes but not the plant density used. Kaleya showed most plasticity in plant height at 4.24 % followed by Dina at 1.69 % and Pan 1867 at 1.02 %. These results are in close conformity with those obtained by Parvez et al. (1989) in soybean who reported that plant height tends to increase slightly with increase in planting density. Studies by Abayomi et al. (2008) and Zubair (2009) on cluster beans showed that plant height was not affected significantly by seed rates. These results however differ with those obtained by Mellendorf (2011) in his study of competition relief. Holmes and Smith, (1977) Sekimura et al. (2000) and Çalifikan et, al. (2007) report that, possible environmental factors explaining increased plant heights in higher plant densities due to reduced row spacing are light quantity and quality resulting in apical dominance set up.

The number of branches per plant was significantly influenced by the varieties as well as plant density. There was a marked reduction in number of branches for all the five varieties, ranging from 4.67 % for Kaleya to 31.88 % for Dina and Magoye, as the plant density was raised from D1 to D3. This was a result of plasticity effect exhibited by the soybean (Squire, 1990). Bullock et al. (1998), Ball et al. (2000), Çalifikan et al. (2007), Mehmet (2008), and Shamsi and Kobraee (2011) all reported finding the number of branches to significantly vary among plant densities and among varieties due to varietal effect. Ayub (2011) found out that increasing the seed rates decreased the number of branches. The reason for having less number of branches at higher seed rates may be due to more competition among plants for light,

space and nutrients at higher seed rates. These results are supported by the findings of Biswas et al. (1997) who observed an inverse relationship between seed rate and number of branches per plant. Consequently, the ability of soybean to branch was greater in wider rows.

The significant differences observed in the chlorophyll content (at V4 and V6 growth stages) and nitrogen content was due to the varietal effects and not due to plant densities employed. These findings are confirmed by those of Bejandi et al. (2012) who found non-significant nitrogen fixation and chlorophyll concentration in inoculated chickpea (*Cicer arietinum* L.) across the three plant densities but among the varieties in their study. Moe (2012) cited that direct linear relationship through extracted leaf chlorophyll and leaf nitrogen concentration was found. On the other hand, Squire, (1990) states that the population density has a moderate effect on the conversion of intercepted radiation to dry matter, but its influence on production is mainly through leaf area index. Additionally, nutrients other than N also affect chlorophyll concentrations (Liu et al. 2012). The results obtained also agree but partially differ with postulations advanced by Makoi et al. (2011) who stated that photosynthesis rates and the associated parameters such as stomata conductance, intercellular CO<sub>2</sub> concentration and transpiration rate, chlorophyll contents,  $\delta^{13}C$  (carbon discrimination) and water-use efficiency (WUE), root growth and nitrate depletion (Marschner, 2012) are affected by several agronomical factors and therefore, changes in plant population in the field, plant arrangements, type of plant species and genotypes involved in such cropping systems would affect photosynthetic parameters. Since high plant density is associated with lower grain yield and dry matter due to decreased photosynthesis rate, it was proposed that low plant density will possibly increase such rates and it was expected, for example, that increasing plant density which leads to increase in shading in the field, leading to limitation in light intensity, would thus, lower the photosynthesis rate and the associated parameters (Makoi et al. 2011).

The N-content showed significant varietal effects, but the main effect of planting density was not significant as was the interaction of the two factors. Kapustka and Wilson (1990) found that an increase in soybean plant density reduced nodule number and dry weight per plant, but maintained higher specific activity per nodule, which resulted in the same values of nitrogen fixation per plant.

Highly significant differences were observed for the days-to-50 % flowering, days to pod filling and days to full maturity among the genotypes. However, there was no effect observed on the plant population densities. This fact has been stated by Egli (1998) that longer seed filling periods are frequently associated with higher yields in many crops due to longer seed filling duration and resulting in a higher harvest index, unless there is a proportionate increase in vegetative matter. The average days to full plant maturity for the varieties SC Safari, Dina, Magoye, Kaleya and Pan 1867 (120, 152, 165, 132 and 117 days) respectively, could explain the reason for the genotypes Magoye, Kaleya and Dina yielding more than the rest. According to Thoenes (2015), soybean plants' sensitivity to day length or their photoperiodism makes their response to day length controls by timing of the transition from vegetative to reproductive or floral development and the rate of physiological development. Varieties differ in their responses to day length. Some varieties flower under relatively short days while others flower under longer days. Varieties have been classified for photoperiod response based upon the ability of the variety to effectively utilize the length of the growing season in a region. The differences in the duration to fifty percent flowering, days to pod filling and days to full maturity can be attributed to genetic variability among the genotypes as reported by Bray (1993) who found similar results in soybeans.

Significant differences among the varieties and plant density were observed for the biomass yield at both R3 and at harvest. Increasing population density from optimal to higher density (D2 to D3) resulted in increased biomass yield with all varieties showing marked increment ranging from 54 % to 101 %, with Kaleya (an indeterminate variety) having the highest biomass yield increment. The results are in conformity with literature reviewed and research conducted by other scholars. Squire (1990), states that the rate at which a stand produces dry matter and the amount produced by the time it is harvested; both depend on many environmental and physiological factors. The main factors, other than solar radiation, that cause differences among the (C<sub>4</sub> and C<sub>3</sub>) plants are plant population density, the composition of the stand and temperature. All these affect the three main attributes of a stand in different ways; these attributes being the leaf area, its conversion ratio for solar radiation and duration. Population density has a moderate effect on the conversion of intercepted radiation to dry matter, but its influence on production is

mainly through leaf area index. Total production therefore increases as population rises, and reaches a plateau when further increase in population results in only slightly more intercepted radiation. Amissah-Arthur et al. (1999) and Ayub et al., (2011) found that dry matter was significantly increased with increase in seeding rates. This increase can be attributed to more plant population at given seed rates. It is also true then than biomass of an individual plant tends to reduce in higher population stands, a fact observed in this study. Sekimura et al. (2000) state that plants exhibit great morphological plasticity in their response to the environment such as the number of neighbouring plants (i.e. population density), therefore, plant height, for instance, increases relative to (individual plant) biomass, stem diameter and leaf area as population density increases.

Significant differences among the five varieties for number of pods per plant, seeds per plant and hundred seed weight were observed. Also, the number of pods per plant and seeds per plant were significantly influenced by the population densities but the hundred seed weight was not. The reduction in plant population from normal plant density to lower plant density (D2 to D1) resulted in the increase in the number of pods per plant and seeds per plant while the increase from normal density to higher density (D2 to D3) resulted in lower number of pods and seeds per plant. Similar results were obtained by Çalifikan et al. (2007), Shamsi and Kobraee (2011) and Bing et al (2010) who reported that grain yield and number of pods per plant were declined with increasing density while Shamsi and Kobraee (2011) recorded more number of pods per plant at lower density.

The significant differences observed in the results for 100 seed weights were due to the five varieties and not due to plant densities employed. This observation was in agreement with what other researchers found. Taha (1988), Board (2000) and Mellendorf (2011) all found that seed mass was not affected by seeding density. Shamsi and Kobraee (2011) stated that variation in 100 grain weight of different legumes may be a genetic or cultivar factor rather than due to environmental effect such as population density. Çalifikan, et al. (2007), reports that although the average mass of an individual seed contributes to final seed yield, seed number per plant is the main component determining final yield. This fact has been shown in the results obtained in this study where Magoye, Kaleya and Dina had higher seed number per plant compared to the other two varieties.

The high mean yields exhibited by genotype Magoye across the three plant densities could be attributed to its high number of pods per plant and number of seeds per plant which remained consistently high compared to the other genotypes across the three environments. The low yield exhibited by genotypes SC Safari and Pan 1867 could be attributed to their shorter stature, shorter growing period and having lower number of pods and seeds per plant. Kato et al. (2015) has stated that the effect of growth type (indeterminate vs. determinate) on yield is often inconsistent. Studies have shown that among the early maturing varieties, indeterminate varieties may tend to out yield determinate types. However, as maturity time increases, the difference is non-significant. The growth habit and yield may tend to vary depending on environments and the genetic background. Ball et al. (2000), Mehmet (2008) and Shamsi and Kobraee (2011) all report that increasing the population reduces yield per plant but increases yield per unit area. The decreased yield per plant is more than offset by population, resulting in yield per square meter increasing to an asymptote as population increases. Kaleya (an indeterminate variety) was the most sensitive (plastic) and showed linear response (Egli, 1988) in terms of yield at 46.80 % followed by Pan 1867 at 17.67 % and Dina at 13.51 %. Despite Magoye having the highest yield overall, it did not respond plastically as density was raised from D2 to D3, SC Safari also showed reduced yields as density was raised from D2 to D3 preferring to yield better in the optimal environment.

Mehmet (2008) has written that in general, seed yield is determined as the product of biomass (BM) and harvest index (HI). However, acknowledging that soybean HI is constant in most environments, maximizing BM should produce the highest yields (Mehmet, 2008). Duncan (1986) also proposed that, the greater the total dry matter (TDM) the greater the yield, as long as the TDM is produced before seed initiation. Furthermore, it has been suggested that optimal crop growth rate (CGR), or dry matter (DM) production, results when leaf area index (LAI) is sufficient (3.0-3.5) to achieve near maximum light interception (LI) of 95 % by R5 (Shamsi and Kobraee, 2011). Martin (1998) reports that large plants tend to bear a large number of seeds. It can therefore be said that the higher average yields obtained from Magoye, Kaleya and Dina could be attributed partly to their higher biomass yields and their plant heights.

Magoye (a determinate cultivar) was the tallest (77.7 cm mean height across plant densities), had the longest growing period (165 days), the most number of pods (40.7 pods/plant), had the most number of seeds (117 seeds/plant) and was self nodulating. These factors may have contributed to Magoye out yielding the other varieties.

There were significant differences among the genotypes for post-harvest seed germination as well as vigour. However, non-significant differences were observed for the plant densities for the two parameters despite results showing slight reduction in germination and vigour with increase in plant density. Similar results were found in an experiment conducted by Shena et al. (2011) where increasing plant population resulted in reduced vigour, but, the differences were not significant at any densities. These results differ from those found by Castillo (1992), where in his experiment with garden peas (*Pisum sativum* L.), seeds from a population of 200 plants/m<sup>2</sup> and 10 cm row width harvested at 15 % seed moisture content had lower vigour than less dense plantings, a fact which was attributed to high temperature and relative humidity within the crop canopy.

The strength of association for traits measured with yield as well as the inter component correlation amongst the components showed that plant height ( $r = 0.584^*$ ), number of pods per plant ( $r = 0.697^*$ ), number of seed per plant ( $r = 0.733^*$ ) and biomass yield at harvest ( $r = 0.598^*$ ), were positively and significantly correlated. To assess the cause and effect of yield in regression analysis, yield was used as the dependent variable while the morpho- physiological traits were used as independent variables. Significant and small contribution to total variations was observed among the independent variables in the study. Biomass yield at harvest had a significant influence on yield having the highest Wald statistic of 99.99 %. Other variables; plant height, number of pod per plant, number of seeds per plant and hundred seed weight showed significant contributions to total variation. Therefore biomass yield had the most influence on the observed yield as reported by Duncan (1986).

## **CHAPTER 6: CONCLUSION AND RECOMMENDATIONS**

### **6.1 Conclusion**

Varying plant density during the whole growth period affected varieties differently for some parameters. An increase in plant density showed a reduction in most parameters under assessment except for yield and biomass. Number of branches, number of pods per plant and number of seeds per plant were reduced with increase in plant density. Varieties with greater potential to perform in elevated plant densities were identified as Kaleya, Pan 1867 and Dina and were seen to be elastic while Magoye and SC Safari were inelastic. There was a strong correlation relationship between yield and plant height, biomass yield, number of pods per plant and number of seeds per plant.

### **6.2 Recommendations**

Varieties of Kaleya, Pan 1867 and Dina can be considered for production under increased plant population after further studies. These studies should be conducted in more than one location and season in order to strengthen the findings.

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## APPENDICES

**Appendix 1: Weather Data for the 2014/2015 Agricultural Season**

Climate Parameter					
Month	Rainfall (mm)	Relative Humidity (%)	Mean Max temp ( <sup>0</sup> C)	Mean Min Temp ( <sup>0</sup> C)	Mean Temp ( <sup>0</sup> C)
October	0	42.5	32.1	16.9	24.5
November	5.4	55.9	33.1	18.2	25.6
December	264.3	78.8	28.2	17.0	22.6
January	147.1	80.0	27.1	16.6	21.8
February	154.7	84.0	28.0	16.2	22.1
March	66.6	79.6	27.9	15.2	21.6
April	99.8	82.3	25.1	14.4	19.8
May	0	69.8	25.8	9.9	17.9
June	0	66.2	24.3	8.5	16.4
July	0	61.6	25.4	9.9	17.6
August	0	47.9	26.9	11.6	19.2
September	0	44.3	31.1	16.5	23.8
<b>Total/mean</b>	<b>737.9</b>	<b>66.1</b>	<b>27.9</b>	<b>14.2</b>	<b>21.1</b>

**Appendix 2:** Means for the ANOVA morphological and physiological traits

Variety	Plant Density	Plant Height (cm)	No. of Branches	Morphological and physiological parameters					Days to pod filling	Days to maturity
				Chlorophyll -V4 (nmol chl/cm <sup>2</sup> )	Chlorophyll-V6 (nmol chl/cm <sup>2</sup> )	N-yield (%)	Days to 50% Flower			
SC Safari	D 1	49.20	4.35	34.07	36.75	2.61	52.00	68.00	121.00	
	D 2	51.80	4.00	33.61	36.55	2.63	52.00	68.00	120.00	
	D 3	48.50	3.05	33.46	37.51	1.75	52.00	68.00	119.00	
	<b>Mean</b>	<b>49.83</b>	<b>3.80</b>	<b>33.71</b>	<b>36.94</b>	<b>2.33</b>	<b>52.00</b>	<b>68.00</b>	<b>120.00</b>	
Dina	D 1	74.30	3.15	30.62	36.15	1.54	67.00	85.00	152.20	
	D 2	77.10	3.45	31.04	33.30	1.29	67.00	85.00	151.80	
	D 3	78.40	2.35	30.47	34.07	1.74	67.00	85.00	151.20	
	<b>Mean</b>	<b>76.60</b>	<b>2.98</b>	<b>30.71</b>	<b>34.51</b>	<b>1.52</b>	<b>67.00</b>	<b>85.00</b>	<b>151.73</b>	
Magoye	D 1	80.50	4.30	28.73	32.06	1.85	65.00	78.00	210.00	
	D 2	75.50	3.45	28.64	31.71	2.66	65.00	77.00	142.20	
	D 3	77.00	2.35	27.85	31.29	1.83	65.00	77.00	141.20	
	<b>Mean</b>	<b>77.67</b>	<b>3.37</b>	<b>28.41</b>	<b>31.69</b>	<b>2.11</b>	<b>65.00</b>	<b>77.33</b>	<b>164.47</b>	
Kaleya	D 1	61.10	5.60	31.72	34.63	3.21	57.00	75.00	132.80	
	D 2	61.20	5.35	32.43	35.01	2.36	57.00	75.00	131.80	
	D 3	63.80	5.10	30.07	35.36	2.04	57.00	75.00	131.00	
	<b>Mean</b>	<b>62.03</b>	<b>5.35</b>	<b>31.41</b>	<b>35.00</b>	<b>2.54</b>	<b>57.00</b>	<b>75.00</b>	<b>131.87</b>	
Pan 1867	D 1	46.20	4.10	33.38	34.33	1.78	47.00	71.00	117.80	
	D 2	49.10	4.65	31.97	36.68	2.39	47.00	70.00	117.20	
	D 3	49.60	3.45	33.85	35.17	1.38	47.00	70.00	116.30	
	<b>Mean</b>	<b>48.30</b>	<b>4.07</b>	<b>33.07</b>	<b>35.39</b>	<b>1.85</b>	<b>47.00</b>	<b>70.33</b>	<b>117.10</b>	
Grand mean		62.9	3.9	31.5	34.7	2.1	57.4	75.2	137.1	

CV (%)	4.4	4.3	2.8	2.4	17.2	0.1	0.1	6.7
LSD (Varieties)	8.11	0.5072	2.144	1.789	0.6193	0.3347	0.3347	28.77
LSD (Plant density)	6.29	0.3929	1.661	1.386	0.4797	0.2593	0.2593	22.29
LSD (Density x varieties)	14.05	0.8784	3.713	3.098	1.0726	0.5798	0.5798	49.84

<b>Morphological and physiological parameters</b>										
<b>Variety</b>	<b>Plant Density</b>	<b>Biomass yield-R3 (kg/m<sup>2</sup>)</b>	<b>Biomass yield-R8 (kg/m<sup>2</sup>)</b>	<b>No. pods/plant</b>	<b>No. seeds/plant</b>	<b>100 seed weight (g)</b>	<b>Yield (ton/ha)</b>	<b>Germination (%)</b>	<b>Vigour (%)</b>	
SC Safari	D 1	3.80	8.56	20.95	40.30	14.70	1.62	91.00	90.00	
	D 2	7.58	15.02	20.65	41.10	14.03	2.28	92.00	90.00	
	D 3	10.32	25.17	15.85	30.60	13.51	2.08	83.00	80.00	
	<b>Mean</b>	<b>7.23</b>	<b>16.25</b>	<b>19.15</b>	<b>37.33</b>	<b>14.08</b>	<b>1.99</b>	<b>88.67</b>	<b>86.67</b>	
Dina	D 1	19.95	9.90	24.80	58.10	15.02	2.46	94.00	90.00	
	D 2	25.45	17.90	22.90	52.30	14.75	2.96	95.00	90.00	
	D 3	26.45	27.57	19.80	42.70	15.14	3.36	96.00	92.00	
	<b>Mean</b>	<b>23.95</b>	<b>18.46</b>	<b>22.50</b>	<b>51.03</b>	<b>14.97</b>	<b>2.93</b>	<b>95.00</b>	<b>90.67</b>	
Magoye	D 1	13.60	11.03	53.15	117.00	11.01	3.62	94.00	89.00	
	D 2	15.01	20.18	41.35	91.00	10.84	3.70	92.00	87.00	
	D 3	27.38	38.12	27.65	60.80	11.27	3.60	86.00	81.00	
	<b>Mean</b>	<b>18.66</b>	<b>23.11</b>	<b>40.72</b>	<b>89.60</b>	<b>11.04</b>	<b>3.64</b>	<b>90.67</b>	<b>85.67</b>	
Kaleya	D 1	10.40	13.94	29.50	64.50	11.48	1.93	97.00	95.00	
	D 2	11.94	19.22	30.80	66.10	11.73	2.97	96.00	93.00	
	D 3	20.29	38.74	32.35	70.40	11.84	4.36	95.00	94.00	
	<b>Mean</b>	<b>14.21</b>	<b>23.97</b>	<b>30.88</b>	<b>67.00</b>	<b>11.68</b>	<b>3.09</b>	<b>96.00</b>	<b>94.00</b>	
Pan 1867	D 1	5.60	8.57	19.60	36.30	18.66	1.84	80.00	76.00	

	D 2	10.60	18.88	19.00	32.60	18.09	2.15	73.00	68.00
	D 3	16.75	24.80	15.95	28.00	17.24	2.53	79.00	73.00
<b>Mean</b>		<b>10.98</b>	<b>17.42</b>	<b>18.18</b>	<b>32.30</b>	<b>18.00</b>	<b>2.17</b>	<b>77.33</b>	<b>72.33</b>
Grand mean		15	19.8	26.3	55.5	14	2.8	89.5	85.9
CV (%)		8.8	8.5	11.2	11.3	3	13.7	3.6	3.5
LSD (Varieties)		5.411	5.434	5.345	12.59	0.827	0.781	5.4	6.007
LSD (Plant density)		4.191	4.209	4.14	9.75	0.641	0.605	4.183	4.653
LSD (Density x varieties)		9.372	9.412	9.258	21.81	1.432	1.353	9.353	10.405

**Appendix 3: Bonferroni/Fisher's Test for Multiple Comparisons**

No.	Parameter	Variety	Means	Comparisons	Density	Means	Comparisons
1	Plant height	Pan 1867	48.3	a	D1	62.25	a
		SC Safari	49.8	a	D2	62.92	a
		Kaleya	62.02	b	D3	63.45	a
		Dina	76.58	c			
		Magoye	77.67	c			
2	Branch/plant	Dina	2.983	a	D3	3.26	a
		Magoye	3.367	ab	D2	4.18	b
		SC Safari	3.8	b	D1	4.3	b
		Pan 1867	4.067	b			
		Kaleya	5.35	c			
3	Chlorophyll Content-V4	Magoye	28.41	a	D3	31.14	a
		Dina	30.71	ab	D2	31.54	a
		Kaleya	31.4	ab	D1	31.7	a
		Pan 1867	33.07	b			
		SC Safari	33.71	b			
4	Chlorophyll Content-V6	Magoye	31.69	a	D2	34.65	a
		Dina	34.51	b	D3	34.68	a
		Kaleya	35	b	D1	34.78	a
		Pan 1867	35.4	b			
		SC Safari	36.94	b			
5	N-Content	Dina	1.521	a	D3	1.746	a
		Pan 1867	1.846	ab	D1	2.195	a
		Magoye	2.113	ab	D2	2.266	a
		SC Safari	2.329	ab			
		Kaleya	2.534	b			
6	Days to 50% Flower	Pan 1867	46.75	a	D1	57.3	a
		SC Safari	51.92	b	D2	57.45	a
		Kaleya	56.92	c	D3	57.5	a
		Magoye	64.67	d			
		Dina	66.83	e			
7	Days to pod filling	SC Safari	68.08	a	D3	75.1	a
		Pan 1867	70.25	b	D2	75.15	a
		Kaleya	75.08	c	D1	75.3	a
		Magoye	77.33	d			
		Dina	85.17	e			
8	Days to	Variety	Means	Comparisons	Density	Means	Comparisons

	<b>Maturity</b>						
		Pan 1867	117.1	a	D3	131.8	a
		SC Safari	120.1	a	D2	132.7	a
		Kaleya	131.8	ab	D1	146.7	a
		Dina	151.8	ab			
		Magoye	164.5	b			
<b>9</b>	<b>Biomass yield at R3</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		SC Safari	7.23	a	D1	10.67	a
		Pan 1867	10.98	ab	D2	14.12	a
		Kaleya	14.21	ab	D3	20.24	b
		Magoye	18.67	bc			
		Dina	23.95	c			
<b>10</b>	<b>Biomass yield harvest</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons (F)</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		SC Safari	16.25	a	D1	10.4	a
		Pan 1867	17.42	a	D2	18.24	b
		Dina	18.24	ab	D3	30.88	c
		Magoye	23.11	bc			
		Kaleya	23.96	c			
<b>11</b>	<b>No. of Pods/plant</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		Pan 1867	18.18	a	D3	22.32	a
		SC Safari	19.15	a	D2	26.94	ab
		Dina	22.5	a	D1	29.6	b
		Kaleya	30.88	b			
		Magoye	40.72	c			
<b>12</b>	<b>No. of Seeds/plant</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		Pan 1867	32.29	a	D3	46.47	a
		SC Safari	37.3	a	D2	56.63	ab
		Dina	50.99	ab	D1	63.22	b
		Kaleya	67.03	b			
		Magoye	89.6	c			
<b>13</b>	<b>100 Seed Weight</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		Magoye	11.04	a	D3	13.8	a
		Kaleya	11.68	a	D2	13.89	a
		SC Safari	14.08	b	D1	14.17	a
		Dina	14.97	b			
		Pan 1867	18	c			
<b>14</b>	<b>Yield</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		SC Safari	1.995	a	D1	2.294	a
		Pan 1867	2.175	a	D2	2.812	ab
		Dina	2.925	ab	D3	3.185	b
		Kaleya	3.085	ab			
		Magoye	3.639	b			
<b>15</b>	<b>Post-harvest Germination</b>	<b>Variety</b>	<b>Means</b>	<b>Comparisons</b>	<b>Density</b>	<b>Means</b>	<b>Comparisons</b>
		Pan 1867	77.42	a	D3	87.75	a

16	Post-harvest seed vigour						
		Variety	Means	Comparisons	Density	Means	Comparisons
		SC Safari	88.67	b	D2	89.5	a
		Magoye	90.67	b	D1	91.2	a
		Dina	94.67	b			
		Kaleya	96	b			
		Pan 1867	72.17	a	D3	83.85	a
		Magoye	85.42	b	D2	85.45	a
		SC Safari	86.5	b	D1	88.1	a
		Dina	90.83	b			
		Kaleya	94.08	b			

**Appendix 4:** Analyses of results in GenStat

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**GenStat Twelfth Edition**  
**GenStat Procedure Library Release PL20.2**

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**Analysis of variance**

**Variate: Plant height (PH)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	341.42	113.81	1.17	
Rep.*Units* stratum					
Variety	4	9490.89	2372.72	24.46	<.001
Density	2	14.51	7.25	0.07	0.928
Variety*Density	8	146.03	18.25	0.19	0.991
Residual	42	4073.90	97.00		
Total	59	14066.75			

Tables of means

Variate: PH

Grand mean: 62.9

Variety	V1	V2	V3	V4	V5
	49.8	76.6	77.7	62.0	48.3
Density	D1	D2	D3		
	62.2	62.9	63.5		
Variety	Density	D1	D2	D3	
V1		49.2	51.8	48.5	
V2		74.3	77.1	78.4	
V3		80.6	75.5	77.0	
V4		61.1	61.2	63.8	
V5		46.2	49.1	49.7	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	2.84	2.20	4.92

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	4.02	3.11	6.96

Least significant differences of means (5% level)

Table	Variety	Density	Variety
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			Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	8.11	6.29	14.05

Stratum standard errors and coefficients of variation

Variate: PH

Stratum	d.f.	s.e.	cv%
Rep	3	2.75	4.4
Rep.*Units*	42	9.85	15.7

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	48.30	a
V1	49.80	a
V4	62.02	b
V2	76.58	c
V3	77.67	c

### Analysis of variance

**Variate: Number of branches (NB)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1.3040	0.4347	1.15	
Rep.*Units* stratum					
Variety	4	39.1693	9.7923	25.84	<.001
Density	2	12.9493	6.4747	17.09	<.001
Variety*Density	8	4.2907	0.5363	1.42	0.218
Residual	42	15.9160	0.3790		
Total	59	73.6293			

Tables of means

Variate: NB

Grand mean: 3.913

Variety	V1	V2	V3	V4	V5
	3.800	2.983	3.367	5.350	4.067
Density	D1	D2	D3		
	4.300	4.180	3.260		
Variety	Density	D1	D2	D3	
V1		4.350	4.000	3.050	
V2		3.150	3.450	2.350	
V3		4.300	3.450	2.350	
V4		5.600	5.350	5.100	
V5		4.100	4.650	3.450	

Standard errors of means

Table	Variety	Density	Variety Density
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rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.1777	0.1377	0.3078

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.2513	0.1947	0.4353

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.5072	0.3929	0.8784

Stratum standard errors and coefficients of variation

Variate: NB

Stratum	d.f.	s.e.	cv%
Rep	3	0.1702	4.3
Rep.*Units*	42	0.6156	15.7

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V2	2.983	a
V3	3.367	ab
V1	3.800	b
V5	4.067	b
V4	5.350	c

**Analysis of variance**

**Variate: Chlorophyll content at V4 (Chl<sub>1</sub>)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	34.257	11.419	1.69	
Rep.*Units* stratum					
Variety	4	210.519	52.630	7.77	<.001
Density	2	3.342	1.671	0.25	0.782
Variety*Density	8	19.328	2.416	0.36	0.937
Residual	42	284.353	6.770		
Total	59	551.800			

Tables of means

Variate: Chl<sub>1</sub>

Grand mean: 31.46

Variety	V1	V2	V3	V4	V5
	33.71	30.71	28.41	31.40	33.07
Density	D1	D2	D3		
	31.70	31.54	31.14		
Variety	Density	D1	D2	D3	
V1		34.07	33.61	33.46	
V2		30.62	31.04	30.47	
V3		28.73	28.64	27.85	
V4		31.72	32.43	30.07	
V5		33.38	31.97	33.85	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.751	0.582	1.301

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	1.062	0.823	1.840

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	2.144	1.661	3.713

Stratum standard errors and coefficients of variation

Variate: Chl<sub>1</sub>

Stratum	d.f.	s.e.	cv%
Rep	3	0.873	2.8
Rep.*Units*	42	2.602	8.3

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V3	28.41	a
V2	30.71	ab
V4	31.40	ab
V5	33.07	b
V1	33.71	b

**Analysis of variance**

**Variate: Chlorophyll content at V6 (Chl<sub>2</sub>)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	30.889	10.296	2.18	
Rep.*Units* stratum					
Variety	4	176.368	44.092	9.35	<.001
Density	2	0.189	0.095	0.02	0.980
Variety*Density	8	32.977	4.122	0.87	0.545
Residual	42	197.970	4.714		
Total	59	438.393			

Tables of means

Variate: Chl<sub>2</sub>

Grand mean: 34.71

Variety	V1	V2	V3	V4	V5
	36.94	34.51	31.69	35.00	35.40
Density	D1	D2	D3		
	34.78	34.65	34.68		
Variety	Density	D1	D2	D3	
V1		36.75	36.55	37.51	
V2		36.15	33.30	34.07	
V3		32.06	31.71	31.29	
V4		34.63	35.01	35.36	
V5		34.33	36.68	35.17	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.627	0.485	1.086

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.886	0.687	1.535

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42

l.s.d. 1.789 1.386 3.098

Stratum standard errors and coefficients of variation

Variate: Chl<sub>2</sub>

Stratum	d.f.	s.e.	cv%
Rep	3	0.829	2.4
Rep.*Units*	42	2.171	6.3

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V3	31.69	a
V2	34.51	b
V4	35.00	b
V5	35.40	b
V1	36.94	b

**Analysis of variance**

**Variate: Nitrogen content (NC)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	5.7231	1.9077	3.38	
Rep.*Units* stratum					
Variety	4	7.6359	1.9090	3.38	0.017
Density	2	3.1828	1.5914	2.82	0.071
Variety*Density	8	6.0083	0.7510	1.33	0.256
Residual	42	23.7292	0.5650		
Total	59	46.2793			

Tables of means

Variate: NC

Grand mean: 2.069

Variety	V1	V2	V3	V4	V5
	2.329	1.521	2.113	2.534	1.846
Density	D1	D2	D3		
	2.195	2.266	1.746		
Variety	Density	D1	D2	D3	
V1		2.607	2.628	1.753	
V2		1.535	1.293	1.735	
V3		1.850	2.663	1.828	
V4		3.208	2.360	2.035	
V5		1.775	2.385	1.378	

Standard errors of means

Table	Variety	Density	Variety Density
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rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.2170	0.1681	0.3758

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.3069	0.2377	0.5315

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.6193	0.4797	1.0726

Stratum standard errors and coefficients of variation

Variate: NC

Stratum	d.f.	s.e.	cv%
Rep	3	0.3566	17.2
Rep.*Units*	42	0.7517	36.3

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V2	1.521	a
V5	1.846	ab
V3	2.113	ab
V1	2.329	ab
V4	2.534	b

**Analysis of variance**

**Variate: Days to 50 % flower (50%DF)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.3167	0.1056	0.64	
Rep.*Units* stratum					
Variety	4	3426.1667	856.5417	5188.67	<.001
Density	2	0.4333	0.2167	1.31	0.280
Variety*Density	8	0.7333	0.0917	0.56	0.808
Residual	42	6.9333	0.1651		
Total	59	3434.5833			

Tables of means

Variate: 50%DF

Grand mean: 57.417

Variety	V1	V2	V3	V4	V5
	51.917	66.833	64.667	56.917	46.750

Density	D1	D2	D3	
	57.300	57.450	57.500	
Variety	Density	D1	D2	D3
V1		51.750	52.000	52.000
V2		67.000	66.750	66.750
V3		64.500	64.750	64.750
V4		56.750	57.000	57.000
V5		46.500	46.750	47.000

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.1173	0.0909	0.2031

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.1659	0.1285	0.2873

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.3347	0.2593	0.5798

Stratum standard errors and coefficients of variation

Variate: 50%DF

Stratum	d.f.	s.e.	cv%
Rep	3	0.0839	0.1
Rep.*Units*	42	0.4063	0.7

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	46.75	a
V1	51.92	b
V4	56.92	c
V3	64.67	d
V2	66.83	e

**Analysis of variance**

**Variate: Days to pod fill (DPF)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.3167	0.1056	0.64	
Rep.*Units* stratum					
Variety	4	2148.5667	537.1417	3253.84	<.001
Density	2	0.4333	0.2167	1.31	0.280
Variety*Density	8	0.7333	0.0917	0.56	0.808
Residual	42	6.9333	0.1651		
Total	59	2156.9833			

Tables of means

Variate: DPF

Grand mean: 75.183

Variety	V1	V2	V3	V4	V5
	68.083	85.167	77.333	75.083	70.250
Density	D1	D2	D3		
	75.300	75.150	75.100		
Variety	Density	D1	D2	D3	
V1		68.250	68.000	68.000	
V2		85.000	85.250	85.250	
V3		77.500	77.250	77.250	
V4		75.250	75.000	75.000	
V5		70.500	70.250	70.000	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.1173	0.0909	0.2031

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.1659	0.1285	0.2873

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.3347	0.2593	0.5798

Stratum standard errors and coefficients of variation

Variate: DPF

Stratum	d.f.	s.e.	cv%
Rep	3	0.0839	0.1
Rep.*Units*	42	0.4063	0.5

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V1	68.08	a
V5	70.25	b
V4	75.08	c
V3	77.33	d
V2	85.17	e

### Analysis of variance

Variate: Days to maturity (DM)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	3745.	1248.	1.02	
Rep.*Units* stratum					
Variety	4	20200.	5050.	4.14	0.006
Density	2	2801.	1400.	1.15	0.327
Variety*Density	8	9640.	1205.	0.99	0.459
Residual	42	51230.	1220.		
Total	59	87617.			

Tables of means

Variate: DM

Grand mean: 137.1

Variety	V1	V2	V3	V4	V5
	120.1	151.8	164.5	131.8	117.1
Density	D1	D2	D3		
	146.7	132.7	131.8		
Variety	Density	D1	D2	D3	
V1		120.8	120.2	119.3	
V2		152.2	151.8	151.2	
V3		210.0	142.2	141.2	
V4		132.8	131.8	131.0	
V5		117.8	117.2	116.3	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	10.08	7.81	17.46

Standard errors of differences of means

Table	Variety	Density	Variety Density
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rep.	12	20	4
d.f.	42	42	42
s.e.d.	14.26	11.04	24.70

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	28.77	22.29	49.84

Stratum standard errors and coefficients of variation

Variate: DM

Stratum	d.f.	s.e.	cv%
Rep	3	9.12	6.7
Rep.*Units*	42	34.93	25.5

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	117.1	a
V1	120.1	a
V4	131.8	ab
V2	151.8	ab
V3	164.5	b

### Analysis of variance

Variate: Biomass at R3 (BM<sub>1</sub>)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	77.71	25.90	0.60	
Rep.*Units* stratum					
Variety	4	2047.94	511.98	11.87	<.001
Density	2	939.75	469.88	10.89	<.001
Variety*Density	8	180.33	22.54	0.52	0.833
Residual	42	1811.74	43.14		
Total	59	5057.46			

Tables of means

Variate: BM<sub>1</sub>

Grand mean: 15.01

Variety	V1	V2	V3	V4	V5
	7.23	23.95	18.67	14.21	10.98
Density	D1	D2	D3		
	10.67	14.12	20.24		
Variety	Density	D1	D2	D3	

V1	3.80	7.58	10.32
V2	19.95	25.45	26.45
V3	13.60	15.01	27.38
V4	10.40	11.94	20.29
V5	5.60	10.60	16.75

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	1.896	1.469	3.284

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	2.681	2.077	4.644

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	5.411	4.191	9.372

Stratum standard errors and coefficients of variation

Variate: BM<sub>1</sub>

Stratum	d.f.	s.e.	cv%
Rep	3	1.314	8.8
Rep.*Units*	42	6.568	43.8

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V1	7.23	a
V5	10.98	ab
V4	14.21	ab
V3	18.67	bc
V2	23.95	c

**Analysis of variance**

**Variate: Canopy biomass at harvest (BM<sub>2</sub>)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	128.63	42.88	0.99	
Rep.*Units* stratum					
Variety	4	580.53	145.13	3.34	0.018
Density	2	4271.12	2135.56	49.09	<.001
Variety*Density	8	340.40	42.55	0.98	0.466
Residual	42	1827.24	43.51		
Total	59	7147.91			

#### Tables of means

Variate: BM<sub>2</sub>

Grand mean: 19.84

Variety	V1	V2	V3	V4	V5
	16.25	18.46	23.11	23.96	17.42
Density	D1	D2	D3		
	10.40	18.24	30.88		
Variety	Density	D1	D2	D3	
V1		8.56	15.02	25.17	
V2		9.90	17.90	27.57	
V3		11.03	20.18	38.12	
V4		13.94	19.22	38.74	
V5		8.57	18.88	24.80	

#### Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	1.904	1.475	3.298

#### Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	2.693	2.086	4.664

#### Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	5.434	4.209	9.412

#### Stratum standard errors and coefficients of variation

Variate: BM <sub>2</sub>			
Stratum	d.f.	s.e.	cv%
Rep	3	1.691	8.5
Rep.*Units*	42	6.596	33.2

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V1	16.25	a
V5	17.42	a
V2	18.46	a
V3	23.11	a
V4	23.96	a

### Analysis of variance

#### Variate: Number of pods/plant (NPD)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	393.34	131.11	3.11	
Rep.*Units* stratum					
Variety	4	4323.47	1080.87	25.68	<.001
Density	2	542.79	271.39	6.45	0.004
Variety*Density	8	923.53	115.44	2.74	0.016
Residual	42	1767.94	42.09		
Total	59	7951.07			

Tables of means

Variate: NPD

Grand mean: 26.29

Variety	V1	V2	V3	V4	V5
	19.15	22.50	40.72	30.88	18.18
Density	D1	D2	D3		
	29.60	26.94	22.32		
Variety	Density	D1	D2	D3	
V1		20.95	20.65	15.85	
V2		24.80	22.90	19.80	
V3		53.15	41.35	27.65	
V4		29.50	30.80	32.35	
V5		19.60	19.00	15.95	

Standard errors of means

	Mean	s.e.mean	Mean	s.e.mean	Mean	s.e.mean
Variety	D1: 300,000 plants/ha		D2: 400,000 plants/ha		D3: 550, 000 plants/ha	
Sc						
Safari	40.26	0.963	41.08	4.382	30.56	3.111
Dina	58.06	12.046	52.25	14.046	42.66	7.493

Magoye	117.03	9.322	91.01	5.122	60.75	10.493
Kaleya	64.51	5.223	66.14	6.534	70.45	13.947
Pan						
1867	36.26	3.651	32.64	5.823	27.95	1.238

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	1.873	1.451	3.244

#### Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	2.649	2.052	4.588

#### Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	5.345	4.140	9.258

#### Stratum standard errors and coefficients of variation

Variate: NPD

Stratum	d.f.	s.e.	cv%
Rep	3	2.956	11.2
Rep.*Units*	42	6.488	24.7

#### Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	18.18	a
V1	19.15	a
V2	22.50	a
V4	30.88	b
V3	40.72	c

#### Analysis of variance

**Variate: Number of seeds/plant (NSD)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1765.0	588.3	2.52	
Rep.*Units* stratum					

Variety	4	26231.6	6557.9	28.07	<.001
Density	2	2847.8	1423.9	6.09	0.005
Variety*Density	8	4470.3	558.8	2.39	0.032
Residual	42	9813.0	233.6		
Total	59	45127.7			

Tables of means

Variate: NSD

Grand mean: 55.4

Variety	V1	V2	V3	V4	V5
	37.3	51.0	89.6	67.0	32.3
Density	D1	D2	D3		
	63.2	56.6	46.5		
Variety	Density	D1	D2	D3	
V1		40.3	41.1	30.6	
V2		58.1	52.3	42.7	
V3		117.0	91.0	60.8	
V4		64.5	66.1	70.4	
V5		36.3	32.6	28.0	

Standard errors of means

	Mean	s.e.mean	Mean	s.e.mean	Mean	s.e.mean
Variety	D1: 300,000 plants/ha		D2: 400,000 plants/ha		D3: 550,000 plants/ha	
Sc						
Safari	40.26	0.963	41.08	4.382	30.56	3.111
Dina	58.06	12.046	52.25	14.046	42.66	7.493
Magoye	117.03	9.322	91.01	5.122	60.75	10.493
Kaleya	64.51	5.223	66.14	6.534	70.45	13.947
Pan						
1867	36.26	3.651	32.64	5.823	27.95	1.238

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	6.24	4.83	10.81

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	12.59	9.75	21.81

Stratum standard errors and coefficients of variation

Variate: NSD

Stratum	d.f.	s.e.	cv%
Rep	3	6.26	11.3
Rep.*Units*	42	15.29	27.6

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	32.29	a
V1	37.30	ab
V2	50.99	bc
V4	67.03	c
V3	89.60	d

**Analysis of variance**

**Variate: Hundred Seed Weight (100SW)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	7.777	2.592	2.57	
Rep.*Units* stratum					
Variety	4	372.291	93.073	92.36	<.001
Density	2	1.530	0.765	0.76	0.474
Variety*Density	8	6.335	0.792	0.79	0.618
Residual	42	42.323	1.008		
Total	59	430.257			

Tables of means

Variate: 100SW

Grand mean: 13.95

Variety	V1	V2	V3	V4	V5
	14.08	14.97	11.04	11.68	18.00
Density	D1	D2	D3		
	14.17	13.89	13.80		

Variety	Density	D1	D2	D3
V1		14.70	14.03	13.51
V2		15.02	14.75	15.14
V3		11.01	10.84	11.27
V4		11.48	11.73	11.84
V5		18.66	18.09	17.24

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.290	0.224	0.502

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.410	0.317	0.710

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.827	0.641	1.432

Stratum standard errors and coefficients of variation

Variate: 100SW

Stratum	d.f.	s.e.	cv%
Rep	3	0.416	3.0
Rep.*Units*	42	1.004	7.2

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V3	11.04	a
V4	11.68	a
V1	14.08	b
V2	14.97	b
V5	18.00	c

**Analysis of variance**

**Variate: Yield (Yd)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	6.4565	2.1522	2.39	
Rep.*Units* stratum					
Variety	4	21.9995	5.4999	6.11	<.001
Density	2	8.0131	4.0065	4.45	0.018
Variety*Density	8	7.3747	0.9218	1.02	0.433
Residual	42	37.7753	0.8994		
Total	59	81.6190			

Tables of means

Variate: Yd

Grand mean: 2.76

Variety	V1	V2	V3	V4	V5
Density	1.99	2.93	3.64	3.08	2.18
	D1	D2	D3		
	2.29	2.81	3.19		

Variety	Density	D1	D2	D3
V1		1.62	2.28	2.08
V2		2.46	2.96	3.36
V3		3.62	3.70	3.60
V4		1.93	2.97	4.36
V5		1.84	2.15	2.53

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	0.274	0.212	0.474

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	0.387	0.300	0.671

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	0.781	0.605	1.353

Stratum standard errors and coefficients of variation

Variate: Yd

Stratum	d.f.	s.e.	cv%
Rep	3	0.379	13.7
Rep.*Units*	42	0.948	34.3

Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V1	1.995	a
V5	2.175	a
V2	2.925	ab
V4	3.085	ab
V3	3.639	b

**Analysis of variance**

**Variate: Germination (G)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	478.05	159.35	3.71	

Rep.*Units* stratum					
Variety	4	2604.07	651.02	15.16	<.001
Density	2	119.03	59.52	1.39	0.261
Variety*Density	8	335.63	41.95	0.98	0.467
Residual	42	1804.20	42.96		
Total	59	5340.98			

Tables of means

Variate: G

Grand mean: 89.48

Variety	V1	V2	V3	V4	V5
	88.67	94.67	90.67	96.00	77.42
Density	D1	D2	D3		
	91.20	89.50	87.75		
Variety	Density	D1	D2	D3	
V1		91.25	91.50	83.25	
V2		93.50	94.75	95.75	
V3		94.25	92.00	85.75	
V4		96.75	96.00	95.25	
V5		80.25	73.25	78.75	

Standard errors of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
e.s.e.	1.892	1.466	3.277

Standard errors of differences of means

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
s.e.d.	2.676	2.073	4.634

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	5.400	4.183	9.353

Stratum standard errors and coefficients of variation

Variate: G

Stratum	d.f.	s.e.	cv%
Rep	3	3.259	3.6
Rep.*Units*	42	6.554	7.3

Bonferroni test

Variety  
Comparison-wise error rate = 0.0050

	Mean	
V5	77.42	a
V1	88.67	b
V3	90.67	b
V2	94.67	b
V4	96.00	b

### Analysis of variance

#### Variate: Seed vigour (SV)

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
Rep stratum		3	408.93		136.31	2.56
Rep.*Units* stratum						
Variety		4	3365.43		841.36	15.82 <.001
Density		2	184.30		92.15	1.73 0.189
Variety*Density		8	397.87		49.73	0.94 0.498
Residual		42	2233.07		53.17	
Total		59	6589.60			

#### Tables of means

Variate: SV

Grand mean: 85.80

Variety	V1	V2	V3	V4	V5
	86.50	90.83	85.42	94.08	72.17
Density	D1	D2	D3		
	88.10	85.45	83.85		
Variety	Density	D1	D2	D3	
V1		90.00	89.75	79.75	
V2		90.25	90.25	92.00	
V3		89.00	86.50	80.75	
V4		95.25	93.25	93.75	
V5		76.00	67.50	73.00	

#### Standard errors of means

Table	Variety	Density
rep.	12	20
d.f.	42	42
e.s.e.	2.105	1.630

#### Standard errors of differences of means

Table	Variety	Density
rep.	12	20
d.f.	42	42
s.e.d.	2.977	2.306

Least significant differences of means (5% level)

Table	Variety	Density	Variety Density
rep.	12	20	4
d.f.	42	42	42
l.s.d.	6.007	4.653	10.405

Stratum standard errors and coefficients of variation

Variate: SV

Stratum	d.f.	s.e.	cv%
Rep	3	3.015	3.5
Rep.*Units*	42	7.292	8.5

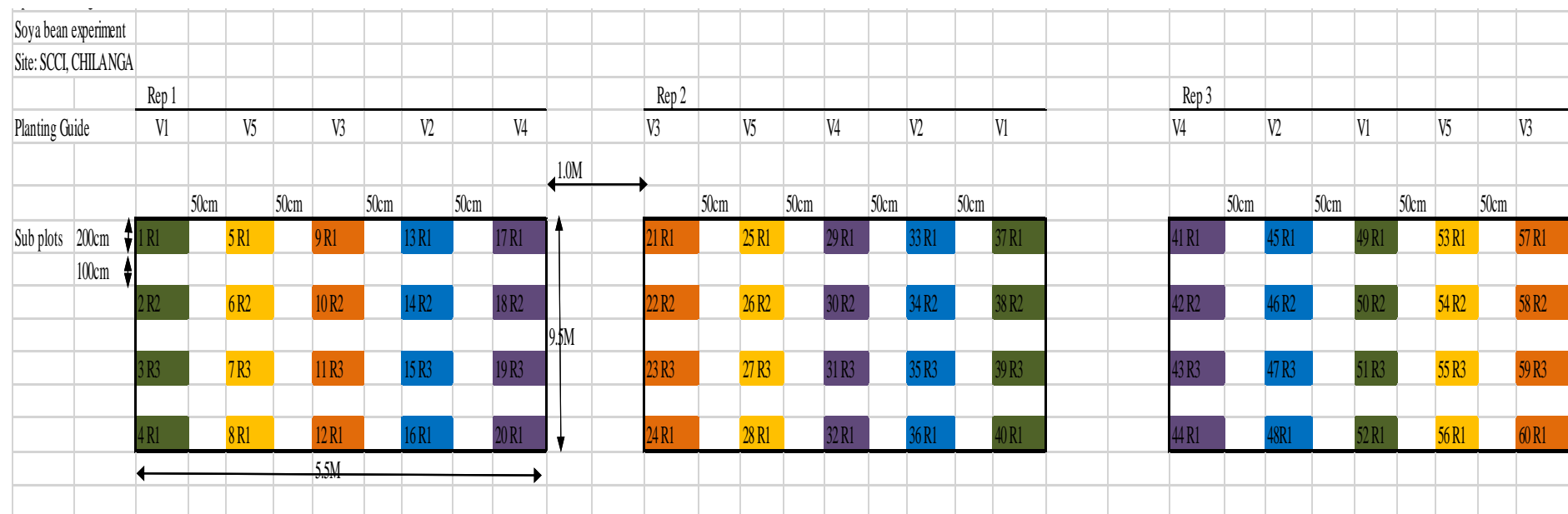
Bonferroni test

Variety

Comparison-wise error rate = 0.0050

	Mean	
V5	72.17	a
V3	85.42	b
V1	86.50	b
V2	90.83	b
V4	94.08	b

**Appendix 5: Field layout in Randomised Complete Block Design (RCBD) in a Two Factorial.**



Where:

**Varieties**

- V1= SC Safari
- V2=Dina
- V3=Magoye
- V4=Kaleya
- V5=Pan 1867

**Planting Density**

- D1 = 300,000 plants/ha
- D2 = 400,000 plants/ha
- D3 = 550,000 plants/ha