EFFECT OF *RHIZOBIUM PHASEOLI* INOCULATION AND PHOSPHORUS APPLICATION ON NODULATION, GROWTH AND YIELD COMPONENTS OF TWO DRYBEAN (*PHASEOLUS VULGARIS*) CULTIVARS

by

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DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of Masters in Science in Agriculture (Agronomy) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

_____ _____

Ndlovu, TJ (Mr) Date

DEDICATION

I dedicate this study to my late brother Walter Ndlovu (1990-2011) who passed on during the inception of this study, may his soul rest in peace.

ACKNOWLEDGEMENTS

I am highly indebted to my supervisors Professor I.K Mariga and my co-supervisor Dr T.P Mafeo for their unrelenting valuable criticism throughout my research. I would also like to give my sincere gratitude to The Agricultural Sector Education and Training Authority (AgriSeta) for providing me with financial support and to the Agricultural Research Council Institute for Soil, Water and Climate (ARC-ISWC) for the provision of meteorological data, which was very useful in completion of this study.

Finally, I would like to thank my family and friends, especially my parents, Bernard and Josphinah Ndlovu who supported and encouraged me throughout my academic endeavours.

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ABSTRACT

Low yields in dry bean are often reported to be associated with lack of inoculation of seeds prior to planting. This also results in little fixed nitrogen contributed by the crop. Soil phosphorus (P) is another important yield limiting factor in most of the dry bean producing regions. Two field experiments were conducted to investigate the response of dry bean cultivars to inoculation and phosphorus application under dryland farming conditions during 2011/2012 and 2012/2013 growing seasons at the Syferkuil farm of University of Limpopo. The experiments were carried out as a split split-plot arrangement in randomized complete block design with four replications. Main plot factor comprised two dry bean cultivars *viz*, red speckled bean and small white haricot. *Rhizobium phaseoli* inoculation levels (inoculated and uninoculated) were assigned in the sub-plot whilst the sub-sub plot was applied with three phosphorus rates at 0, 45 and 90 kg P kg/ha. Growth parameters, phenological characteristics and yield data were collected during the course of the experiments. The results of the two experiments showed that there was no interactive effect of treatments on growth and yield parameters. However, there was a significant interactive effect of cultivar and inoculation on phenological characteristics in both growing seasons. Main effects of cultivar and inoculation significantly affected most of the parameters measured. Inoculated red speckled bean produced tallest plants which reached 50% flowering and maturity earlier than the small white haricot variety. In both growing seasons grain yield was significantly different between the two cultivars ($P \leq 0.01$). The red speckled bean produced higher grain yield of 1657 kg ha^{-1} and 2547 kg ha^{-1} in 2011/2012 and 2012/2013, respectively. In contrast, the small white haricot bean achieved grain yield of 1396 kg/ha and 1797 kg/ha in the respective seasons. Grain yield was significantly increased by approximately 16.15% and 27.50% with *Rhizobium* inoculation in the respective seasons. Phosphorus application at varying rates did not have a significant influence on all parameters measured the experiment in both 2011/2012 and 2012/2013 seasons.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Dry beans are the most widely cultivated species of *Phaseolus* in terms of tons of crop produced per year and the second most important leguminous crop in the world after soya bean (Department of Agriculture, Forestry and Fisheries-DAFF, 2010). In South Africa, dry bean is currently considered as one of the most important field crops on account of its high protein content and dietary fibre benefits (Liebenberg, 2002). According to the Statistics and Economic Analysis (2012), dry beans in South Africa are produced in Mpumalanga, Gauteng, Free State, North West, Limpopo, KwaZulu-Natal and Northern Cape provinces, with Free State, Mpumalanga and Limpopo provinces contributing 36%, 25% and 12%, respectively, of dry bean produced during the 2008/2009 production season.

The red speckled dry bean variety is widely cultivated in South Africa and commands the biggest market share, followed by large white kidney bean and small white canning bean (DAFF, 2010). The level of production of dry beans does not meet local demand hence South Africa imports dry beans to an average value of about R120 million per annum with the imports originating mainly from Asia, America and Europe, while imports from Africa are at a minimum level (Statistics and Economic Analysis, 2012). The potential for dry bean production in the Limpopo province is moderate and the crop is cultivated for local consumption and commercial purposes mostly by small scale farmers, who have farms composed of small units of land about 1.0 hectare in size and mainly used for subsistence farming (Thomas, 2003).

Poor crop stands and low yields in dry bean have been reported to be associated with lack of inoculation of seeds prior to planting which also results in little nitrogen contributed to the crop (Atemkeng *et al*., 2011). Several reports showed that inoculation of seeds with commercial inoculants increased yield in most important legume crops worldwide such as soybean (Thao *et al.,* 2002), cowpea (Ankomah *et al.,* 1996) and groundnut (Anuar *et al.,* 1995). *Rhizobium* inoculation also serves as a cheaper and usually more effective agronomic practice for ensuring adequate nitrogen nutrition of legumes than the application of nitrogen fertilizer (Wange, 1989).

Fageria *et al*. (2002) and Wortmann *et al*. (1998) further indicated that low soil fertility is another important yield limiting factor in most of the dry bean producing regions, with phosphorus deficiency serving as a major nutrient factor severely limiting dry bean production in soils having high iron or aluminium oxide contents. One of the causes of declining soil fertility is continuous cropping without the use of either organic or inorganic fertilizers (Mabapa *et al*., 2010), especially in smallholder farming sectors. According to Kimani *et al.* (2007) soil phosphorus has been identified as the most frequently deficient nutrient and its supply is low in 65% and 80% of the bean production areas of eastern and southern Africa, respectively. It is also estimated that the production losses due to low availability of soil phosphorus in the above mentioned areas is about 1.0 million metric tonnes.

Studies elsewhere clearly indicate that the response of legumes to inoculation, coupled with phosphorus fertilizer application, results in maximum grain yield production when irrigation is applied throughout the season. Thus, it was proposed in this study to use both phosphorus fertilizer and inoculation to determine the nodulation, growth and yield components of dry bean under dryland farming conditions in Limpopo province where majority of farmers depend solely on erratic rainfall which ranges between 400 to 495 mm per annum.

1.2 Problem statement

There is currently no documented information regarding the response of dry bean to inoculation and phosphorus fertilizer application under dryland conditions in Limpopo province.

1.3 Motivation of the study

Identifying appropriate phosphorus fertilizer application rates in combination with the use of inoculation of dry bean seeds by *Rhizobium phaseoli,* would be useful in developing effective phosphorus management for low phosphorus soils and the importance of using inoculants for enhanced management practices to sustain crop production and for improving dry bean yield under dryland conditions.

1.4 Aim and objectives of the study

1.4.1 Aim

To investigate effect of *Rhizobium phaseoli* inoculation and phosphorus application on nodulation, growth and yield components of two dry bean cultivars

1.4.2 Objectives of the study were to determine:

Objective 1: Effect of *Rhizobium phaseoli* inoculation on nodulation, growth and yield components of dry bean.

Objective 2: Effect of phosphorous application on nodulation, growth and yield components of dry bean.

Objective 3: Effect of dry bean cultivar on nodulation, growth and yield components of dry bean.

Objective 4: Interactive effect of *Rhizobium phaseoli* inoculation and phosphorous application on nodulation, growth and yield components of dry bean.

Objective 5: Interactive effect of dry bean cultivar and *Rhizobium phaseoli* inoculation on nodulation, growth and yield components of dry bean.

Objective 6: Interactive effect of dry bean cultivar and phosphorus application on nodulation, growth and yield components of dry bean.

Objective 7: Interactive effect of dry bean cultivar, phosphorus application and *Rhizobium phaseoli* inoculation on nodulation, growth and yield components of dry bean.

1.5 Hypotheses of the study:

Hypothesis 1: *Rhizobium phaseoli* inoculation has no effect on nodulation, growth and yield components of dry bean.

Hypothesis 2: Phosphorus fertilizer application has no effect on nodulation, growth and yield components of dry bean.

Hypothesis 3: Dry bean cultivar has no effect on nodulation, growth and yield components of dry bean

Hypothesis 4: There is no interactive effect of *Rhizobium phaseoli* and phosphorous application on nodulation, growth and yield of dry

bean

Hypothesis 5: There is no interactive effect of dry bean cultivar and *Rhizobium phaseoli* inoculation on nodulation, growth and yield components of dry bean.

Hypothesis 6: There is no interaction effect of dry bean cultivar and phosphorus application on nodulation, growth and yield components of dry bean

Hypothesis 7: There is no interaction effect of dry bean cultivar, phosphorus application and *Rhizobium phaseoli* inoculation on nodulation, growth and yield components of dry bean.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Dry bean is a self-pollinating leguminous crop which belongs to the family Fabaceae and considered as an important crop worldwide, especially in areas with high population density (Nleya *et al.,* 2001). It is believed to have originated from Central and Southern America (Swaider *et al.*, 1992). According to Graham and Ranalli (1997), dry beans are likely to have spread into Africa during the slave trade and colonial periods, and into the north-eastern United States through migration. Dry bean is currently grown throughout the world and comprises many grain classes such as kidney bean, navy bean, cranberry, pinto bean, marrow bean and haricot beans (Gepts, 1998). Despite many grain classes, its low yield is a significant problem (Fernández-Luqueño, *et al*., 2012).

2.2 Plant description and characteristics of dry bean cultivars

2.2.1 Growth habit

Two growth habits are said to be found in edible dry bean, which are classified as determinate (bush) and indeterminate (vining or trailing) growth habits (ARC-Grain Crop Institute, 2010). In addition to the distinction between determinate and indeterminate plant types, three plant growth habits have been identified. The type 1 which has determinate growth habit is characterised by having long stem which ceases when terminal flower emerge on the apex of the main stem or when lateral branches have developed. Type 2 has indeterminate growth habit where vegetative growth continues after flowering or pod filling. The type 3 dry bean also has indeterminate growth habit with very long and flat running side branches. According to Werner (2005) indeterminate dry bean plants fix more atmospheric nitrogen than determinate ones.

2.2.2 Adaptation

Dry beans are well adapted to tropics, subtropics, and warm temperate regions, grown from 40°S to 40°N latitude (International Centre for Tropical Agriculture, 2000). The length of growing season ranges from 85 to 115 days, however, this

depends on cultivar type and night temperatures during the growing season. It grows optimally at temperatures of 18 to 24°C. The maximum temperature during flowering should not exceed 30°C. Day temperatures below 20°C would delay maturity and cause development of empty mature pods. When the crop is cultivated under rainfed conditions it requires a minimum of 400 to 500 mm of rain during the growing season, but an annual total of 600 to 650 mm is considered ideal. Dry beans are said to be planted in warm soils with minimum temperatures preferably above 13°C after all danger of frost has passed. They perform best on sandy loam, sandy clay loam or clay loam with good drainage and clay content between 15 and 35%. Soils with pH (H_2O) of 5.8 to 6.5 are considered to be the best. They would also not grow well in soils that are compacted (DAFF, 2010).

2.3 Utilization of dry bean

The common dry bean is of global agronomic and dietary importance, and its utilization patterns vary dramatically by geographic region and among cultures (Uebersax, 2006). This crop is commonly used for human consumption, animal feed and for soil fertility amelioration through biological nitrogen fixation and green manure (DAFF, 2010). Dry beans are often consumed as dried cooked seeds or as leaf vegetable in combination with such energy sources as maize, plantains or root crops as a source of protein to complement these starchy foods (Broughton *et al*., 2003). Succulent dry bean plants can be used as green manure when ploughed into the soil to increase organic matter of soil. In addition, intercropping dry bean with non-legume crops such as cereals (maize, millet or sorghum), bananas and plantains or root and tuber crops is common practice in developing countries to sustain low input agricultural systems (Broughton *et al*., 2003). Research work has shown that total grain and plant-nitrogen (N) yields could be significantly increased by intercropping legumes with non-legumes (Barker and Blamey, 1985).

2.4 Biological nitrogen fixation (BNF)

Biological nitrogen fixation is very efficient in satisfying the high nitrogen requirements of legumes because the conversion of gaseous nitrogen (N_2) to ammonia (NH_3) takes place inside the plant. Legumes have the unique ability to form a symbiotic relationship with rhizobia bacteria to convert atmospheric nitrogen gas to ammonia nitrogen, a form usable by the plant (Erker and Brick, 1996). Dupont *et al*.

(2012) explain that soon after legume seeds germinate, rhizobia present in the soil or added as seed inoculum invade the root hairs and move through an infection thread toward the root. The bacteria multiply rapidly in the root, causing the swelling of root cells to form nodules. Nitrogen in the air of soil pores around the nodules is fixed by binding it to other elements, and thus, changing it into a plant available form. Some of the carbohydrates manufactured by the plant through photosynthesis are transported to the nodules where they are used as a source of energy by the rhizobia. The rhizobia also use some of the carbohydrates as a source of hydrogen in the conversion of atmospheric nitrogen to ammonia.

Despite BNF being a naturally occurring process, many soils do not have sufficient numbers of appropriate rhizobia for effective symbioses (Silva and Uchida, 2000). Inoculation of leguminous crops with appropriate and compatible rhizobia ensures maximum BNF. Inoculation simply refers to the application of suitable rhizobia to the seed or soil when planting. Inoculation is almost always needed when certain new leguminous crops are introduced to new areas or regions. It is often beneficial to inoculate newly developed or introduced cultivars of legumes even though the same species might have been grown previously (Food and Agriculture Organization, 1984).

2.5 Factors affecting the response of legumes to inoculation and biological nitrogen fixation

2.5.1 Soil temperature

Temperature plays an important role in the success of BNF due to its effect on survival and or growth rate of microorganisms. Temperature has been reported to affect nodulation, survival and persistence of rhizobial strains in soil (Kabahuma, 2013). According to Drew *et al.* (2012), rhizobia are killed in the soil and on seed when soil temperatures exceed 35°C. Effective nodule development and nitrogenase activities are also completely inhibited at low temperature of 8°C (Bordeleau and Prévost, 1994). Nitrogenase activities are high around 12–35°C and reach maximum at 20–25°C in most legumes (Liu *et al.,* 2010). Hungria and Franco (1993) further reported that nodules of common bean formed at high temperatures of 40°C were ineffective and plants were not able to accumulate nitrogen in shoots.

2.5.2 Soil moisture status

Both deficit and excessive soil moisture levels have negative impact on inoculation and BNF. Low soil water potentials inhibit nodulation and growth of rhizobia (Kabahuma, 2013). Singh and Kataria (2012) found that water stress resulted in marked decrease in leghemoglobin, nitrate and nitrite contents and the activity of enzymes of nitrogen assimilation such as nitrate reductase and nitrite reductase in two chickpea genotypes. Streeter (2003) reported a depression of 30–40% of nitrogen content in leaves and pods of soybean plants when irrigation was withheld for four weeks during the reproductive stage. Excessive moisture and waterlogging prevent the development of root hairs and sites of nodulation, and interfere with a normal diffusion of oxygen in the root system of plants (Mulongoy, 1995). The results presented by Youn *et al*. (2008) showed that waterlogging reduced number of nodules and nodule dry weight of super nodulating soybean mutants.

2.5.3 Soil pH

Legume and rhizobial growth are affected by soil pH. Most leguminous plants require a neutral or only a slightly acid soil pH for growth with nodulation problems to be expected once the pH falls below 5.5 (Bordeleau and Prévost, 1994). The optimum pH range for rhizobial growth is between 6.0 and 7.0 (Graham *et al*., 1994). In soils with pH below 5.0 aluminium and manganese become an additional stress which could kill the rhizobia (Drew *et al*., (2012). According to Vassileva *et al*. (1997), low soil pH of 4.0-4.5 extremely reduced number of nodules, nodule dry weight, nodule fresh weight and nitrogenase activity of common bean. On the other hand, Sulieman and Hago (2009) discovered that failure of nodulation in common bean was due to high calcareous soil which prevailed at pH of 8.1 and 8.5 in the top soil and subsoil, respectively.

2.5.4 Mineral nutrition

Legume growth and the function of the legume and *Rhizobium* symbiosis might be affected by a multitude of nutrient disorders, including both deficiencies and toxicities (Chalk *et al*., 2010). Phosphorus is one of several elements which affects nitrogen fixation, and along with nitrogen, it is a principal yield limiting nutrient in many regions of the world (Pereira and Bliss, 1989). Low phosphorus levels in acidic soils,

for example, delay nodulation and infection of primary roots (Mullen *et al*., 1988). Available nitrogen in the soil is another important factor for BNF. The high levels of nitrogen inhibit the *Rhizobium* infection process and also its nitrogen fixation (Mulongoy, 1995). Aluminum and manganese toxicity and low levels of calcium inhibit growth of rhizobia and nodulation at soil pH less than 5 (Bordeleau and Prévost, 1994; Drew *et al*., 2012).

2.5.5 Diversity of indigenous soil rhizobia

Crop responses to inoculation with selected strains of *Rhizobium* are often low, frequently due to the high competitive ability of native strains (V´asquez-Arroyo *et al*., 1998). Indigenous soil rhizobia might differ in population density and infectivity from place to place ranging from < 10 to 107 cells g^{-1} of soil (Abdula, 2013). Further, rhizobia or bradyrhizobia strains differ in their ability to survive and nodulate different hosts or cultivars under different soil conditions. Aliyu et *al*. (2013) found that the insignificant response of cowpea to inoculation was due to the competition between indigenous population and the inoculants. The competition between inoculated and indigenous rhizobia was reported to be influenced by the high population and size of indigenous rhizobia. Large native rhizobial populations often occur when legume crops are grown in the same field for many crop cycles or when crops have been previously inoculated and the rhizobia still persist (Singleton *et al*., 1990).

2.6 Amount of fixed nitrogen

The extent or amount of nitrogen fixed varies according to the legume species and variety. According to Dakora and Keya (1997), grain legumes fix about 15-210 kgN/ha seasonally in Africa. Dry bean however, is said to be a poor fixer of nitrogen in comparison to other legumes with rates as low as 20 kg N/ha (Manrique *et al.,* 1993). According to Tsai *et al*. (1993), most commonly used dry bean cultivars exhibit a high dependence on nitrogen fertilizers for growth and yield, and show considerable variation in their ability to nodulate and fix nitrogen, with the nitrogen percentage derived from atmosphere ranging from 68-72% for the superior cultivars. This indicates that dry beans need starter nitrogen fertilization for sufficient nitrogen fixation. The amount of this starter nitrogen must be in relation to available soil nitrogen.

2.7 Work done on the research problem

2.7.1 Effect of *Rhizobium* inoculation on nodulation, crop growth and yield components

Farmers in many parts of the world have received dramatic increases in yields due to inoculating their legumes (Cigdem and Merih, 2008). Inoculation of seeds by *Rhizobium spp* prior to planting has also been reported to be a key factor in enhancing nodulation, early emergence, crop vigour and high grain yield (Figueiredo *et al.,* 2008 and Otieno *et al.,* 2009). The study conducted by Mbugua *et al.* (2009) on effects of commercial *Rhizobium* strain inoculants and triple superphosphate fertilizer on yield of new dry bean lines in central Kenya showed that bean seeds inoculated with *Rhizobium* strain had higher daily germination count, crop vigour, number of seeds per pod and grain yield as compared with those of uninoculated crops.

Furthermore, comparable results were obtained by Bambara and Ndakidemi (2010) who reported high dry bean seed yield of 1679 kg/ha with inoculated crop compared to 758 kg/ha from the control. These authors further indicated that higher yields obtained with inoculation confirm that the *Rhizobium* technology is efficient in supplying nitrogen to legumes and is a better option for resource-poor farmers who cannot afford to purchase expensive inputs. However, the findings of these two studies were contrary to those of Musandu and Ogendo (2001) who stated that there was no significant difference observed in yield and yield components of dry bean between inoculated and uninoculated crops. According to Silva and Uchida (2000), negative results were associated with inoculation failure due to loss of viability of *Rhizobia* in the inoculant caused by exposure to heat or prolonged storage, environmental and management factors. Inoculation effectiveness is also reduced when soil nitrogen sources are high enough to meet the crop nitrogen requirements or soils have many native *Rhizobia* that can infect the plant and fix nitrogen for the crop.

2.7.2 Effect of phosphorus fertilizer on nodulation, crop growth and yield components

Phosphorus is an essential nutrient both as a part of several key plant structural compounds and as a catalyst in numerous key biochemical reactions in plants. It is

also noted especially for its role in capturing and converting the sun's energy into useful plant compounds (Cordell *et al.,* 2009). When phosphorus is limited in the soil, the most striking effects are a reduction in leaf expansion and leaf surface area, as well as the number of leaves. The deficiency of phosphorus might also limit nitrogen fixation through its effects on growth and survival of rhizobia, nodule formation, nodule functioning and host plant growth (Tang *et al*., 2001).

The study conducted by Zafar *et al.* (2011) to investigate the influence of integrated phosphorus supply and plant growth promoting rhizobacteria on growth, nodulation, yield and nutrient uptake in *Phaseolus vulgaris* indicated that two mineral phosphorus fertilizers at rate of 60 kg P/ha diammonium phosphate and triple super phosphate increased plant height, number of nodules per plant, nodule fresh weight and nodule dry weight. Serraj *et al*. (1998) further specified that nodule establishment and function are important sinks for phosphorus, and nodules usually have the highest phosphorus content in the plant. Therefore, phosphorus deficiency conditions result in reduced symbiotic nitrogen fixation potential and phosphorus fertilization would usually result in enhanced nodule number and mass, as well as greater nitrogen fixation activity per plant.

Rahman *et al.* (2007) also observed highest number of pods per plant, pod length and pod circumference of French bean with the treatment that received 60 kg P/ha as compared to 0 and 40 kg P/ha while El-Gizawy and Mehasen (2009) recorded highest plant height, number of branches, 100 seed weight and seed yield per plant of faba bean (*Vacia faba*) with application of 30 kg P/ha. Nevertheless, Liebenberg (2002) reported that under commercial production the yield responses to phosphorus fertilization are not dramatic in dry beans, and phosphorus is not normally a yield-restrictive factor. However, under subsistence production, where small quantities of fertilizer are applied, phosphorus can be a yield-limiting factor. This suggests that phosphorus requirements for maximum yield production might vary in terms of nutritional status of the soil.

CHAPTER 3
MATERIALS AND METHODS

3.1 Study location

Two experiments were conducted at the Syferkuil farm of the University of Limpopo (23◦ 59' 35" S, 29◦ 33' 46" E) during 2011/2012 and 2012/2013 growing seasons. The climatic condition of the study location is classified as semi-arid with annual precipitation of ±495 mm per annum (Moshia *et al.*, 2008). The soil at Syferkuil farm is a sandy loam with 77–81% sand in the 0–60 cm depth and soil depth varying from 90 to 120 cm (Whitbread and Ayisi, 2004). The daily temperature ranges from 12 to 35°C during the summer planting season (Mpangane *et al.,* 2004).

3.2 Experimental design, treatments and procedures

The field experiments were carried out as split split-plots arranged in a Randomized Complete Block Design (RCBD) with four replications. The treatment factors were: (i) Main plot factor – dry bean cultivars (red speckled and small white haricot beans), (ii) Sub-plot factor - *Rhizobium phaseoli* inoculation levels (with and without inoculation) and (iii) Sub-sub plot factor - phosphorus fertilizer rates using single superphosphate (10.5% P) at 0, 45 and 90 kg P/ha, which gave a total of twelve treatment combinations. Each plot was measuring 3 m × 3.6 m with six rows at inter-and-intra-row spacings of 0.6 m and 0.15 m, respectively.

Dry bean seeds of the inoculation treatment were inoculated with *Rhizobium* inoculum containing *Rhizobium leguminosarum biovar phaseoli* bacteria (5 x 10^8 live cells/g) supplied by STIMUPLANT CC (Zwavelpoort, South Africa). The inoculant was mixed with water and sticker and applied to the seeds as slurry at the rate of 200 g for 50 kg seeds. The slurry was thoroughly mixed with seeds under the shade until the all seeds were fully coated and thereafter sown immediately and covered with soil to avoid exposure to direct sunlight and dehydration. The fertilizer rates were applied according to their treatment arrangement at planting to the side of the rows to avoid direct contact with the seeds and seeds were planted into the moist soil. The experiments received irrigation of 30 mm soon after planting to ensure good crop emergence. In both growing seasons, supplementary irrigation was supplied at 45 mm when drought spells prevailed using the sprinkler irrigation system. The

experiments were kept weed free throughout the growing seasons and sprayed with Malathion 50% emulsifiable concentrate (E.C.) to control insect pests.

3.3 Soil sampling

Soil samples were randomly collected during both planting seasons at the sampling depth of 0 - 15 cm and 15 - 30 cm respectively across the field at planting and harvest maturity using a soil auger. Soil samples at each depth were mixed to make a composite sample. Chemical soil analysis was done on soil pH, total nitrogen, phosphorus, potassium, calcium, magnesium and sodium. Soil pH was determined using the glass electrode pH meter. The total nitrogen determination was done according to the Kjeldahl (1883) digestion procedure while the available phosphorus was determined using Bray 1 method as described by Bray and Kurtz (1945). Determination of exchangeable cations potassium, calcium, magnesium and sodium were measured using a flame photometer at the University of Limpopo Soil Science Laboratory.

3.4 Meteorological data

The rainfall and temperature data at Syferkuil farm during both 2011/2012 and 2012/2013 growing seasons was supplied by the Agricultural Research Council Institute for Soil, Climate and Water (ARC-ISCW).

3.4 Data collection

The representative data were collected from the two middle rows of each plot in the experiment which comprised a net plot size of 1.2 m x 1.8 m having 24 plant population. The following parameters were either calculated or measured:

Days to 50% emergence were recorded when 50% or more plants had emerged in the plot. Days taken to reach 50% flowering were monitored and recorded when 50% or more plants had developed flowers. Days to physiological maturity were recorded when the pods turned brown in colour and seeds shook loose. At 50% flowering, five representative plants from each net plot where dug and separated into roots and shoots. The roots were carefully washed with water to remove the soil. The nodules were picked from the roots, counted and recorded. The root nodules were then oven dried at 65°C for 24 hours for nodule dry weight determination. The number of pods

per plant and number of seeds per pod were counted from six consecutive plants within the net plot at harvest maturity. Hundred seed weight was determined by weighing two samples of 100 seed per plot. Unshelled and shelled weight was determined using the electronic weighing balance (Adam, model: CBK 8H). Grain yield per hectare was extrapolated from seed yield per plot. The total above ground biomass was determined from the net plot using electronic weighing balance at harvest maturity. Number of branches per plant were counted and recorded at physiological maturity. Plant height and pod length were measured using a ruler at harvest maturity.

Harvest index (HI) was calculated using the formula:

$$HI = \frac{\text{Grain yield}}{\text{Total above ground biomass}}$$

Shelling percentage (SP) was calculated using the formula:

$$SP = \frac{\text{Shelled grain weight}}{\text{Unshelled pod weight}} \times 100$$

3.5 Data analysis

The data were subjected to analysis of variance using general linear model of analytical software (STATISTIX 9.0, Tallahassee, Florida. USA), while the mean separation for treatments was done using the Tukey's Honestly Significance Difference (HSD) at 5% level of significance.

CHAPTER 4
RESULTS

The results presented in this chapter are from both 2011/2012 and 2012/2013 growing seasons.

4.1 Chemical soil analyses

4.1.1 Pre-plant and at harvest chemical soil analyses in 2011/2012 growing season

The results for chemical soil analyses for both pre-planting and at harvest are presented in Table 4.1. The analysis of pre-planting soil samples in 2011/2012 season showed that soil pH was moderately acidic (6.3) at sampling depth of 0-15 cm and showed moderately alkaline soil of pH 7.6 with increasing sampling depth of 15-30 cm. Soil samples at harvest show slightly acidic soil of pH 6.5 and slightly alkaline soil of pH 7.3 at sampling depth of 0-15 cm and 15-30 cm, respectively. At sampling depth of 0-15 cm pre-planting soil analysis revealed TN, P, and K levels of 391, 32 and 156 mg/kg, respectively, which exceed the levels required for dry bean. In the subsoil the values for TN, P and K decreased by approximately 25.8, 28.1 and 19.9 %, respectively. At harvest TN, P and K levels were much lower compared to samples analysed at planting. The TN, P and K levels were 283, 28 and 102 mg/kg in the topsoil and 209, 20 and 86 mg/kg in the subsoil, respectively. Pre-plant and at harvest soil analyses in 2011/2012 seasons at varying sampling depth showed that values for Ca, Mg and Na were above critical levels according to Marx *et al*. (1999). High levels might suggest high usage of fertilizers from previous seasons in this experimental site.

4.1.2 Pre-plant and at harvest chemical soil analyses in 2012/2013 growing season

Soil pH at pre-planting in 2012/2013 season was moderately acidic at both sampling depths of 0-15 and 15-30 cm, respectively (Table 4.1). However, soil analysis at harvest was only moderately acidic at 0-15 cm and neutral at 15-30 cm. Similar to 2011/2012 season, TN, P and K at pre-planting showed high values above critical levels required for dry bean of 385, 38 and 102 mg/kg and 316, 31 and 92 mg/kg at 0-15 and 15-30 cm, respectively. Soil analysis at harvest showed more reduced levels of TN, P and K. The levels for TN, P and K at 15-30 cm at harvest were reduced by approximately 44, 38.9 and 21%, respectively. This showed that most of

the nutrients in this soil were saturated in the top soil. The 2011/2012 season exchangeable Ca, Mg and Na cations at both 0-15 and 15- 30 cm were above the critical levels.

Table 4.1 Chemical soil analysis prior planting and at harvest

	2011/2012 season							
	Depths	Parameters						
	(cm)	pH (H_2O)	TN	P	K	Ca	Mg	Na
					mg/kg			
Pre-planting	0-15	6.3	391	32	156	455	302	60
	15-30	7.6	290	23	125	440	289	43
At harvest	0-15	6.5	283	28	102	386	296	56
	15-30	7.3	209	20	86	365	265	35
	2012/2013 season							
	Depths	Parameters						
	(cm)	pH (H_2O)	TN	P	K	Ca	Mg	Na
					mg/kg			
Pre-planting	0-15	6.0	385	38	102	401	288	50
	15-30	6.4	316	31	92	374	225	41
At harvest	0-15	6.2	312	36	100	377	262	44
	15-30	7.0	206	22	79	319	195	36

TN = total nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Na = sodium

4.2 Climatic conditions

4.2.1 Rainfall and temperature in 2011/2012 growing season

Figure 4.1 and 4.2 present climatic data of rainfall and temperature during 2011/2012 and 2012/2013 growing seasons. The total rainfall received during 2011/2012 growing season (PD to PM) was 81.53 mm. The highest and the lowest monthly average rainfall were recorded during December 2011 and February 2012 at 78.23 mm and 3.3 mm, respectively (Figure 4.1). At 50% flowering (January) and 50% physiological maturity (March) periods, no rainfall was received at the experimental farm. Monthly average maximum temperature of 32.01°C was recorded in February,

whilst the average minimum temperature was recorded in March at 13.24°C. Generally, both mean maximum and minimum monthly temperatures started falling towards days to reach 50% physiological maturity.

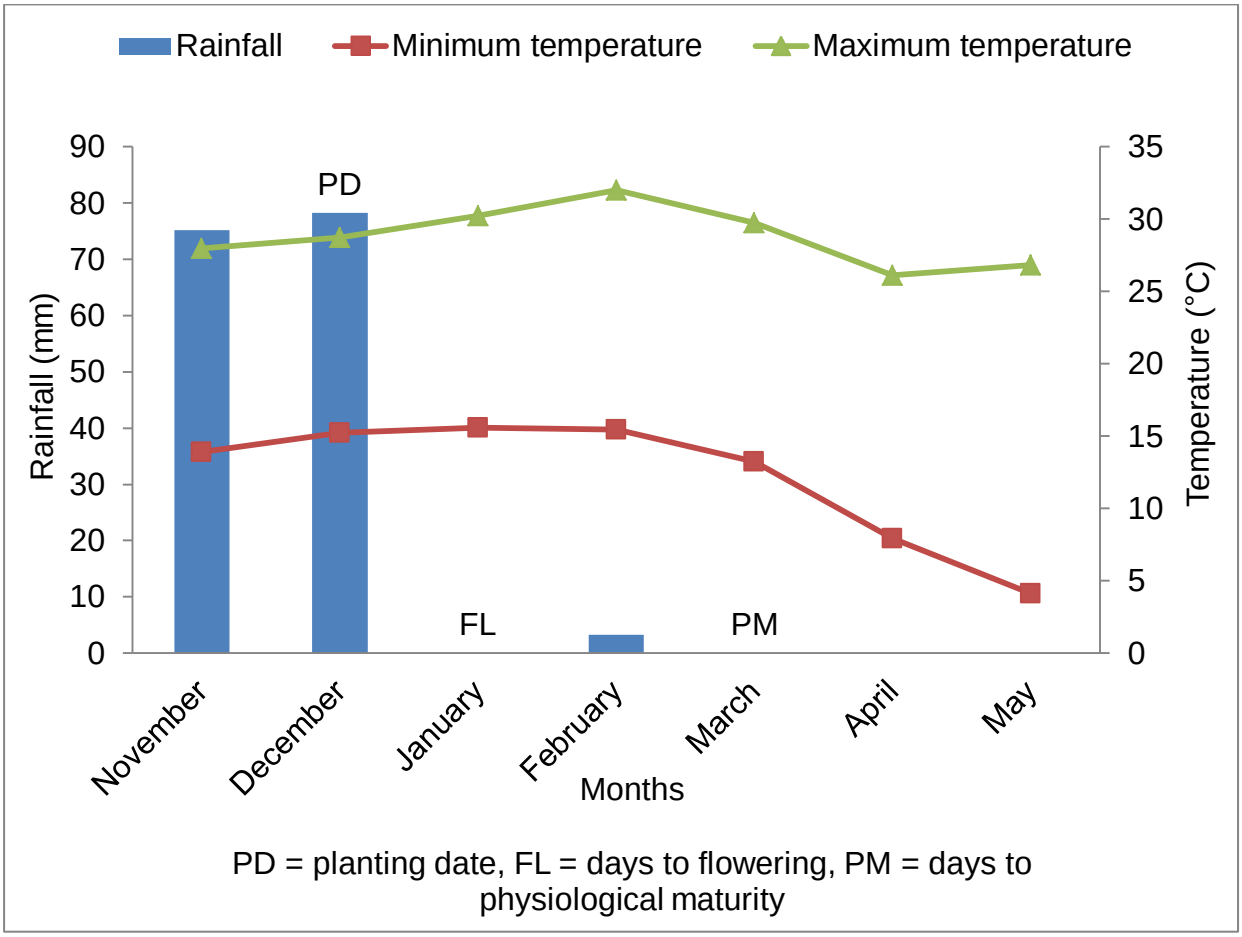

Figure 4.1: Monthly average rainfall, minimum and maximum temperatures at Syferkuil farm in 2011/2012 growing season

4.2.2 Rainfall and temperature in 2012/2013 growing season

During 2012/2013 season rainfall was received during the whole growing period with total of 343.4 mm for PD to PM (Figure 4.2). The highest mean monthly rainfall of 188.45 mm was recorded in January during flowering stage while the lowest average monthly rainfall (44.19 mm) was received during physiological maturity period in March. The highest average maximum monthly temperature of 29.66°C and the lowest average minimum monthly temperature of 12.71°C were received in February and March, respectively. Decline of both maximum and minimum monthly average temperatures were also recorded towards March in 2012/2013 season (Figure 4.2).

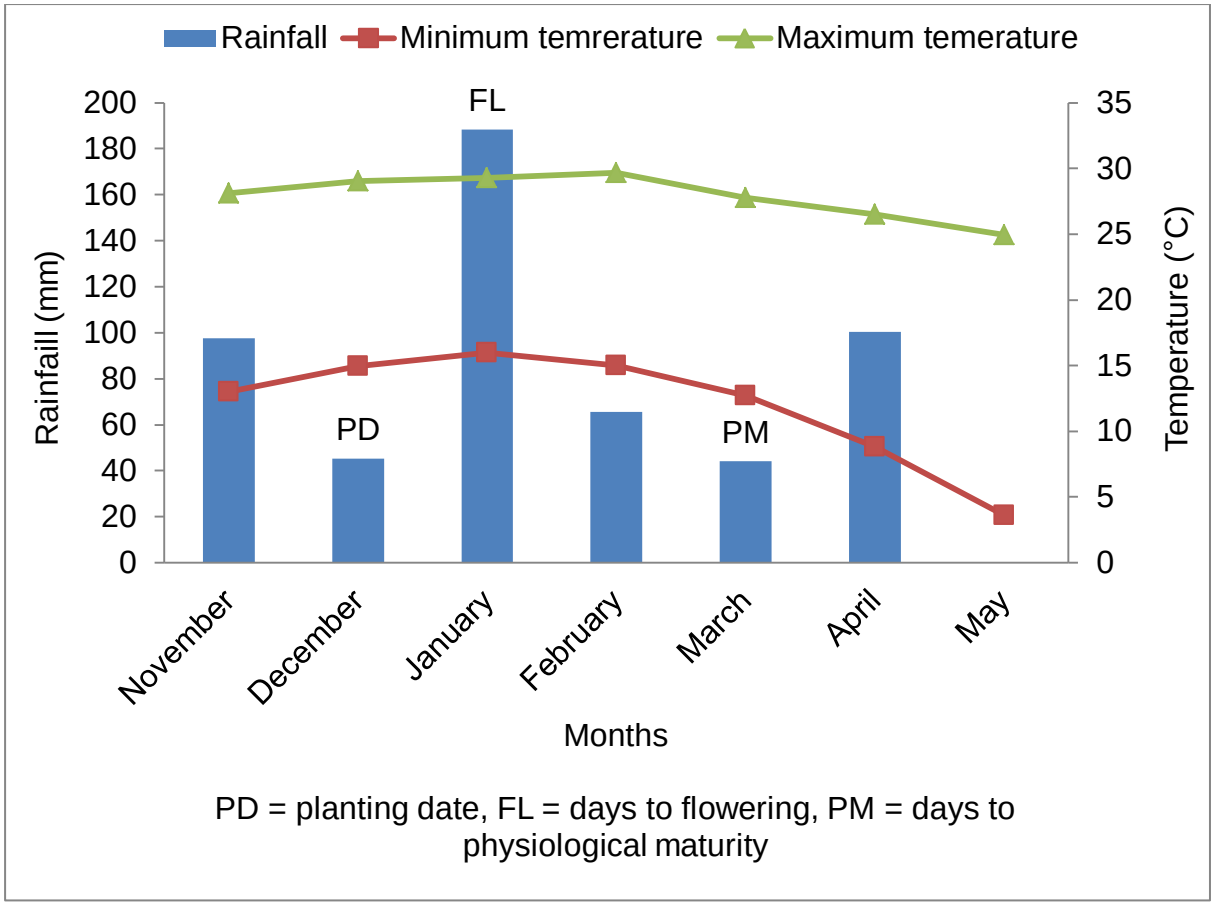

Figure 4.2: Monthly average rainfall, minimum and maximum temperatures at Syferkuil farm in 2012/2013 growing season

4.3. Days to 50% emergence, 50% flowering and 50% physiological maturity

The results for days to 50% emergence, 50% flowering and 50% physiological maturity during 2011/2012 and 2012/2013 growing seasons are presented in Table 4.2. Dry bean cultivars significantly differed in days to 50% emergence, 50% flowering and 50% physiological maturity. The red speckled bean emerged first at 9 days after planting (DAP) whilst the small white haricot emerged at 13 DAP in 2011/2012 growing season. However, days to emergence between the two cultivars did not differ significantly in 2012/2013 season. Flowering at 50% was observed first with the red speckled bean cultivar in both growing seasons ($P \leq 0.05$). In 2011/2012 season, the red speckled bean reached flowering at 44 DAP followed by the small white haricot at 51 DAP and in 2012/2013 season, 50% to flowering was observed at 57 DAP and 61 DAP in the red speckled bean and white haricot, respectively (Table 4.2). The red speckled beans reached physiological maturity early at 94 DAP as

compared to 97 days in small white haricot during 2011/2012 growing season (Table 4.2). In 2012/2013 season, early physiological maturity was also observed at 95 DAP with the red speckled bean, followed by small white haricot at 97 DAP. Inoculation had no significant influence on days to 50 % emergence, but significantly affected days to 50% flowering and 50% physiological maturity in both growing seasons (Table 4.2). Inoculation caused significant decrease ($P \leq 0.01$) in days to flowering from 46 DAP (inoculated) to 49 (uninoculated) in 2011/2012 growing season, and also from 58 DAP (inoculated) to 61 DAP (uninoculated) in 2012/2013 growing season ($P \leq 0.05$). During 2011/2012 season, physiological maturity at 94 DAP was observed with inoculated treatment followed by uninocated treatment at 97 DAP. Similar results were obtained in 2012/2013 growing season, with inoculated treatment reaching early physiological maturity at 95 DAP followed by uninoculated treatment at 98 DAP (Table 4.2). Phosphorus fertilization at varying application rates did not show any significant association with days to 50% emergence, flowering and physiological maturity at $P \leq 0.05$.

On days to 50% emergence, 50% flowering and 50% physiological maturity, phosphorus interaction with cultivar, phosphorus interaction with inoculation, phosphorus interaction with cultivar and inoculation were not significant at $P \leq 0.05$ (Appendices 8.1, 8.2, 8.3, 8.16, 8.17 and 8.18). Table 4.3 shows the interactive effect of cultivar and inoculation on days to 50% emergence, 50% flowering and 50% physiological maturity on dry bean during 2011/2012 and 2012/2013 growing seasons. Interactive effect of dry bean cultivars and inoculation did not have an influence on days to emergence in both successive seasons (Table 4.3). In 2011/2012 season, inoculated red speckled bean reached 50% days to flowering at 44 DAP but did not differ significantly with uninoculated red speckled bean but reached flowering earlier than white haricot at 48 and 54 DAP, respectively. The interactive effect of dry bean cultivars and inoculation did not have a significant influence on days to 50% flowering during the 2012/2013 season (Table 4.3). Days to 50% physiological maturity did not differ significantly among inoculated red speckled bean, uninoculated red speckled and inoculated small white haricot in both growing seasons. Uninoculated small white haricot achieved late physiological maturity at 99 DAP in both seasons.

Table 4.2: Effect of cultivar, inoculation and phosphorus fertilization on days to 50% emergence, 50% flowering and 50% physiological maturity of dry bean during 2011/2012 and 2012/2013 growing seasons

	2011/2012 season			2012/2013 season		
Treatments	Days to 50% emergence	Days to 50% flowering	Days to 50% physiological maturity	Days to 50% emergence	Days to 50% flowering	Days to 50% physiological maturity
Cultivar						
Red speckled	9b	44b	94b	10a	57b	95a
Small white haricot	13a	51a	97a	10a	61a	97b
Significant	**	*	**	ns	*	*
Tukey's HSD	1.23	5.09	2.18	—	3.16	1.61
Inoculation						
Inoculated	11a	46b	94b	10a	58b	95b
Uninoculated	11a	49a	97a	10a	61a	98a
Significant	ns	**	**	ns	*	**
Tukey's HSD	—	1.93	1.78	—	2.71	1.38
Phosphorus						
0 kg/ha	11a	48a	95a	10a	59a	96a
45 kg/ha	11a	47a	96a	10a	59a	96a
90 kg/ha	11a	47a	95a	11a	60a	96a
Significant	ns	ns	ns	ns	ns	ns
Tukey's HSD	—	—	—	—	—	—

N: B. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, * = P ≤ 0.05, ** = P ≤ 0.01, ns = non-significant (P ≤ 0.05).

Table 4.3: Interactive effect of cultivar and inoculation on days to 50% emergence, 50% flowering and 50% physiological maturity of dry bean during 2011/2012 and 2012/2013 growing season

		2011/2012 season			2012/2013 season		
Treatments		Days to 50% emergence	Days to 50% flowering	Days to 50% physiological maturity	Days to 50% emergence	Days to 50% flowering	Days to 50% physiological maturity
Cultivar	**Inoculation**						
Red speckled	Inoculated	9a	44c	93b	10a	56a	95b
Red speckled	Uninoculated	9a	44c	94b	10a	58a	96b
Small white haricot	Inoculated	13a	48b	95b	10a	60a	95b
Small white haricot	Uninocolated	13a	54a	99a	11a	63a	99a
Significant		ns	*	*	ns	ns	*
Tukey's HSD		—	3.87	3.55	—	—	2.78

N: B. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, * = P ≤ 0.05, ns = non-significant (P ≤ 0.05).

4.4 Nodulation

Nodulation was not influenced by the interactive effects between cultivar x inoculation, cultivar x phosphorus, inoculation x phosphorus, and cultivar x inoculation x phosphorus in both 2011/2012 and 2012/2013 growing seasons (Appendices 8.4, 8.5, 8.19 and 8.20) There was no significant difference observed in number of nodules per plant and nodule dry weight between the two cultivars in 2011/2012 season. Cultivar significantly affected number of nodules per plant and nodule dry weight in 2012/2013 growing season (Table 4.4). Number of nodules per plant and nodule dry weight was approximately 47.04% and 71.43% higher in red speckled bean, than in small white haricot, respectively. Nodulation was significantly affected by inoculation with *Rhizobium phaseoli*. Higher mean number of nodules per plant was obtained with inoculation in both growing seasons. Lower values of 21.0 and 38.5 number of nodules per plant were observed with uninoculated treatment in respective seasons. Inoculation with *Rhizobium phaseoli* did not significantly affect nodule dry weight per plant during 2011/2012 season. Nodule dry weight per plant was significantly ($P \leq 0.01$) increased by approximately 51.11% with inoculation compared to uninoculated treatment in 2012/2013 season (Table 4.4). Both number of nodules and nodule dry weight were not affected by phosphorus fertilization in both growing seasons at $P \leq 0.05$.

Table 4.4: Nodulation of dry bean as affected by cultivar, inoculation and phosphorus application during 2011/2012 and 2012/2013 growing seasons

	2011/2012 season		**2012/2013 season**	
Treatments	Number of nodules per plant	Nodule dry weight (g/plant)	Number of nodules per plant	Nodule dry weight (g/plant)
Cultivar				
Red speckled	30.0a	0.21a	54.9a	0.72a
Small white haricot	22.0a	0.26a	37.3b	0.42b
Significant	ns	ns	**	*
Tukey's HSD	—	—	8.82	0.23
Inoculation				
Inoculated	31.0a	0.25a	53.7a	0.68a
Uninoculated	21.0b	0.22a	38.5b	0.45b
Significant	*	ns	**	**
Tukey's HSD	9.92	—	10.33	0.15
Phosphorus				
0 kg/ha	25.6a	0.18a	40.5a	0.47a
45 kg/ha	28.4a	0.30a	51.2a	0.60a
90 kg/ha	24.0a	0.22a	46.7a	0.63a
Significant	ns	ns	ns	ns
Tukey's HSD	—	—	—	—

N: B. Means followed by the same letter in a column are not significantly different at $P \leq 0.05$, * = significant ($P \leq 0.05$), ** = significant ($P \leq 0.01$), ns = non-significant ($P \leq 0.05$).

4.5 Number of branches per plant, plant height and pod length

There was no significant interactive effect of cultivar x inoculation, cultivar x phosphorus, inoculation x phosphorus and cultivar x inoculation x phosphorus on number of branches per plant, plant height and pod length during both 2011/2012 and 2012/2013 seasons (Appendices 8.6, 8.7, 8.8, 8.21, 8.22 and 8.23). The number of branches per plant and plant height did not differ significantly between the two cultivars in 2011/2012 growing season (Table 4.5). The red speckled bean produced pod length of 20% longer than of small white haricot in 2011/2012 season. During 2012/2013 season, there was no significant difference in number of branches per plant between the two cultivars. Cultivar significantly ($P \leq 0.01$) affected plant height and pod length in 2012/2013 season. The red speckled bean had taller plants of 71.43 cm with long pods of 11.99 cm as compared to small white haricot having plant height of 52.17 cm and pod length of 9.52 cm. Inoculation did not significantly influence number of branches per plant, plant height and pod length in 2011/2012 growing season (Table 4.5). In 2012/2013 season inoculation only affected plant height. Tallest plants of 66.51 cm were observed on plant inoculated with *Rhizobium phaseoli* compared to uninoculated plant having plant height of 57.09 cm. Phosphorus fertilization did not have a significant influence on number of branches per plant, plant height and pod length in both growing seasons (Table 4.5).

Table 4.5: Effect of cultivar, inoculation and phosphorus fertilization on number of branches, plant height and pod length of dry bean during 2011/2012 and 2012/2013 seasons

	2011/2012 season			2012/2013 season		
Treatments	Number of branches per plant	Plant height (cm)	Pod length (cm)	Number of branches per plant	Plant height (cm)	Pod length (cm)
Cultivar						
Red speckled	3.70a	68.35a	10.80a	5.00a	71.43a	11.99a
Small white haricot	3.34a	53.79a	9.00b	4.70a	52.17b	9.52b
Significant	ns	ns	*	ns	**	**
Tukey's HSD	__	__	1.33	__	8.00	0.51
Inoculation						
Inoculated	3.53a	61.49a	9.97a	4.71a	66.51a	10.84a
Uninoculated	3.50a	60.65a	9.81a	4.99a	57.09b	10.67a
Significant	ns	ns	ns	ns	**	ns
Tukey's HSD	__	__	__	__	5.38	__
Phosphorus						
0 kg/ha	3.57a	60.02a	10.00a	4.80a	62.60a	10.85a
45 kg/ha	3.39a	61.74a	9.90a	5.05a	60.78a	10.93a
90 kg/ha	3.60a	61.46a	9.77a	4.73a	62.04a	10.49a
Significant	ns	ns	ns	ns	ns	ns
Tukey's HSD	__	__	__	__	__	__

N: B. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, * = P ≤ 0.05, ** = P ≤ 0.01, ns = non-significant (P ≤ 0.05).

4.6 Yield components and grain yield in 2011/2012 growing season

Table 4.6 shows the main effects of cultivar, inoculation and phosphorus application on yield components of dry bean during 2011/2012 growing season. Cultivar significantly affected number of pods per plant, hundred seed weight, grain yield and total above ground biomass. The red speckled bean produced about 15.1 pods per plant, whilst small white haricot had 12.6 pods per plant. Hundred seed weight, grain yield and total above ground biomass of the red speckled bean were approximately 128.79%, 18.69% and 38.17% respectively, higher than of values for small white haricot. There were no significant differences observed in number of seeds per pod, shelling percentage and harvest index between the two cultivars (Table 4.6). Inoculation with *Rhizobium phaseoli* yielded hundred seed weight of 34.1 g and grain yield of 1640 kg/ha, which were higher than hundred seed weight of 31.0 g and grain yield of 1412 kg/ha without *Rhizobium phaseoli* inoculation. Number of pods per plant, number of seeds per pod, shelling percentage, harvest index and total above ground biomass were not influenced by inoculation at $P \leq 0.05$. There were no significant differences observed for all parameters measured at different phosphorus application rates (Table 4.6).

The yield components and grain yield of dry bean in 2011/2012 season were not significantly affected by the interactive effect of cultivar x phosphorus, inoculation x phosphorus and cultivar x inoculation x phosphorus (Appendices 8.9, 8.10, 8.11, 8.12, 8.13, 8.14, and 8.15). Results for the interactive effect of cultivar and inoculation on yield components of dry bean in 2011/2012 growing season are presented in Table 4.7. The interaction between cultivar and inoculation significantly affected hundred seed weight. Inoculated red speckled bean produced highest mean value of 48.1 g followed by uninoculated red speckled bean at 42.4 g. Hundred seed weight of both inoculated and uninoculated small white haricot did not differ significantly but were significantly lower than those for red speckled bean. Number of pods per plant, number of seeds per pod, grain yield, shelling percentage, harvest index and total above ground biomass were not influenced by the interactive effect of cultivar and inoculation (Table 4.7).

Table 4.6: Effect of cultivar, inoculation and phosphorus fertilization on yield components and grain yield of dry bean in 2011/2012 growing season

Treatments	Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg/ha)	Shelling (%)	Harvest index	Total above ground biomass (kg/ha)
Cultivar							
Red speckled	15.1a	4.6a	45.3a	1657a	68.2a	0.50a	3316a
Small white haricot	12. 6b	4.3a	19.8b	1396b	67.6a	0.59a	2400b
Significant	*	ns	**	**	ns	ns	**
Tukey's HSD	2.32	—	3.15	106.46	—	—	408.22
Inoculation							
Inoculated	13.8a	4.5a	34.1a	1640a	68.1a	0.57a	2926a
Uninoculated	13.8a	4.4a	31.0b	1412b	67.7a	0.51a	2789a
Significant	ns	ns	**	*	ns	ns	ns
Tukey's HSD	—	—	2.00	209.79	—	—	—
Phosphorus							
0 kg/ha	13.6a	4.6a	33.2a	1559a	67.6a	0.53a	2984a
45 kg/ha	14.4a	4.6a	31.7a	1536a	67.3a	0.55a	2820a
90 kg/ha	13.5a	4.2a	32.8a	1483a	68.8a	0.54a	2768a
Significant	ns	ns	ns	ns	ns	ns	ns
Tukey's HSD	—	—	—	—	—	—	—

N: B. Means followed by the same letter in a column are not significantly different at $P \leq 0.05$, *= $P \leq 0.05$, ** = $P \leq 0.01$, ns = non-significant ($P \leq 0.05$).

Table 4.7: Interactive effect of cultivar and inoculation on yield components and grain yield of dry bean in 2011/2012 growing season

Treatments		Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)	Grain yield Kg/ha	Shelling (%)	Harvest index	Total above ground biomass (kg/ha)
Cultivar	**Inoculation**							
Red speckled	Inoculated	15.6	4.7	48.0a	1814	68.2	0.53	3463
Red speckled	Uninoculated	14.6	4.6	42.4b	1500	68.2	0.47	3168
Small white haricot	Inoculated	12.1	4.3	20.1c	1467	68.1	0.62	2410
Small white haricot	Unincolated	13.0	4.3	19.5c	1324	67.1	0.55	2389
Significant		ns	ns	*	ns	ns	ns	ns
Tukey's HSD		—	—	5.48	—	—	—	—

N: B. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, * = P ≤ 0.05 ns = non-significant (P ≤ 0.05).

4.7 Yield components and grain yield in 2012/2013 growing season

In 2012/2013 season no interactive effect was observed for cultivar x inoculation, cultivar x phosphorus, inoculation x phosphorus and cultivar x inoculation x phosphorus on yield components of dry bean (Appendices 8.24, 8.25, 8.26, 8.27, 8.28, 8.29 and 8.30). Table 4.8 shows the main effects of cultivar, inoculation and phosphorus fertilization on yield components of dry bean in 2012/2013 growing season. Number of pods per plant, number of seeds per pod, shelling percentage and harvest index did not differ significantly between the red speckled bean and small white haricot cultivars. The red speckled bean achieved superior hundred seed weight of 48.3 g and grain yield of 2547 kg/ha, as compared to the small white haricot, which produced hundred seed weight of 26.2 g and grain yield of 1797 kg/ha. The total above ground biomass of the red speckled bean was approximately 27.75% higher than of small white haricot. Inoculation significantly ($P \leq 0.01$) affected grain yield and total above ground biomass, but did not have any influence on number of pods per plant, number of seeds per pod, hundred seed weight, shelling percentage and harvest index (Table 4.8). High grain yield of 2434 kg/ha and total above ground biomass of 3830 kg/ha ($P \leq 0.01$) were observed with inoculated treatment, whilst uninoculated treatment showed low grain yield of 1909 kg/ha and total above ground biomass of 3263 kg/ha. This translated to gains of 27.5 and 17.4% for grain yield and total above ground biomass, respectively. Phosphorus fertilization did not have any effect on all parameters measured at $P \leq 0.05$.

Table 4.8: Effect of cultivar, inoculation and phosphorus fertilization on yield components and grain yield of dry bean in 2012/2013 growing season

Treatments	Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg/ha)	Shelling (%)	Harvest index	Total above ground biomass (kg/ha)
Cultivar							
Red speckled	15.5a	4.2a	48.3a	2547a	73.9a	0.64a	3979a
Small white haricot	18.7a	4.5a	26.2b	1797b	75.5a	0.58a	3114b
Significant	ns	ns	**	**	ns	ns	*
Tukey's HSD	—	—	4.85	117.21	—	—	794.20
Inoculation							
Inoculated	17.1a	4.3a	37.3a	2434a	74.8a	0.63a	3830a
Uninoculated	17.0a	4.4a	37.2a	1909b	74.5a	0.59a	3263b
Significant	ns	ns	ns	**	ns	ns	**
Tukey's HSD	—	—	—	352.58	—	—	395.14
Phosphorus							
0 kg/ha	16.2a	4.3a	37.0a	2151a	73.9a	0.63a	3435a
45 kg/ha	18.2a	4.4a	37.1a	2225a	75.8a	0.58a	3766a
90 kg/ha	16.8a	4.3a	37.6a	2139a	74.3a	0.62a	3439a
Significant	ns	ns	ns	ns	ns	ns	ns
Tukey's HSD	—	—	—	—	—	—	—

N: B. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, * = P ≤ 0.05, ** = P ≤ 0.01, ns = non-significant (P ≤ 0.05)

4.8 Correlations among dry bean variables in 2011/2012 growing season

Correlation among ten dry bean variables in both 2011/2012 and 2012/2013 are presented in Tables 4.9 and 4.10, respectively. A significantly positive ($P \leq 0.001$) correlation was observed between the total above ground biomass and number of pods per plant ($R^2 = 0.36$), hundred seed weight ($R^2 = 058$), grain yield ($R^2 = 0.64$) and plant height ($R^2 = 0.22$). Total above ground biomass was negatively correlated with days to 50% emergence and days to physiological maturity. Days to 50% emergence was positively correlated ($P \leq 0.001$) with days to 50% flowering and days to physiological maturity, whilst number of pods per plant and hundred seed weight were found to be negatively and significantly correlated to days to 50% emergence. Days to 50% flowering and days to physiological maturity were negatively and significantly correlated with number of pods per plant, hundred seed weight, grain yield and plant height (Table 4.9). Number of nodules per plant was only correlated with two variables. Number of nodules was negatively and significantly correlated to days to physiological maturity and positively correlated to grain yield at P value of 0.05. Nodule dry weight did not show any correlation with all variables. Grain yield showed a positive significant ($P \leq 0.001$) correlation with hundred seed weight ($R^2 = 0.28$) and plant height ($R^2 = 0.08$).

Table 4.9: Correlation analysis among ten dependent dry bean variables in 2011/2012 season

Variables	BIOM	DAYEM	DAYFL	DAYPHY	NNOD	NODW	NOPP	SW	GY
BIOM									
DAYEM	-0.56***								
DAYFL	-0.35**	0.51***							
DAYPHY	-0.47***	0.47***	0.51**						
NNOD	0.18	-0.00	-0.12	-0.25*					
NODW	-0.10	-0.02	-0.25	-0.14	0.02				
NOPP	0.60***	-0.35**	-0.54***	-0.44***	0.25	0.05			
SW	0.76***	-0.72***	-0.66***	-0.55***	0.06	0.09	0.53***		
GY	0.80***	-0.24	-0.32*	-0.43**	0.28*	-0.02	0.64***	0.53***	
PH	0.47***	-0.48	-0.41**	-0.32*	0.06	0.18	0.23	0.56***	0.28

* = P ≤ 0.05, ** = P ≤ 0.01, *** = P ≤ 0.001

BIOM = total above ground biomass, DAYE = days to 50% emergence, DAYFL = days to 50% flowering, DAYPHY = days to 50% physiological maturity, NNOD = number of nodules per plant, NODW = nodule dry weight, NOPP = number of pods per plant, SW = 100 seed weight, GY = grain yield, PH = plant height

4.9 Correlations among dry bean variables in 2012/2013 growing season

Significantly positive correlation was observed between the total above ground biomass and number of nodules per plant (R^2 = 0.26), nodule dry weight (R^2 = 0.15), hundred seed weight (R^2 = 0.35), grain yield (R^2 = 0.64) and plant height (R^2 = 0.49) (Table 4.10). Grain yield showed a significant positive correlation with hundred seed weight (R^2 = 0.31) and plant height (R^2 = 0.45) at P value of 0.001. The total above ground biomass was negatively associated with days to 50% flowering and days to 50% physiological maturity. Days to 50% emergence were not associated with any variable (Table 4.10). Days to 50% flowering showed a positive association ($P \leq 0.001$) with days to physiological maturity. Both days to 50% flowering and physiological maturity were significantly negatively correlated with number of nodules per plant, nodule dry weight, hundred seed weight, grain yield and plant height. A significant negative correlation was observed between number of pods per plant and nodule dry weight, hundred seed weight and plant height. There was a positive association ($P \leq 0.001$) with both number of nodules per plant and nodule dry weight on hundred seed weight, grain yield and plant height.

Table 4.10: Correlation analysis among ten dependent dry bean variables in 2012/2013 season

Variables	BIOM	DAYEM	DAYFL	DAYPHY	NNOD	NODW	NOPP	SW	GY
BIOM									
DAYEM	0.04								
DAYFL	-0.63***	0.09							
DAYPHY	-0.45***	0.27	0.57***						
NNOD	0.51***	-0.25	-0.58***	-0.61***					
NODW	0.39**	-0.27	-0.58***	-0.45***	0.49***				
NOPP	0.00	0.15	0.10	0.11	-0.23	-0.29*			
SW	0.59***	-0.17	-0.55***	-0.32*	0.47***	0.50***	-0.36**		
GY	0.80***	0.00	-0.58***	-0.47***	0.48***	0.45***	-0.15	0.56***	
PH	0.70***	-0.07	-0.64***	-0.54***	0.58***	0.54***	-0.33*	0.69***	0.66***

* = P ≤ 0.05, ** = P ≤ 0.01, *** = P ≤ 0.001

BIOM = total above ground biomass, DAYE = days to 50% emergence, DAYFL = days to 50% flowering, DAYPHY = days to 50% physiological maturity, NNOD=number of nodules per plant, NODW=nodule dry weight, NOPP = number of pods per plant, SW = 100 seed weight, GY = grain yield, PH = plant height

CHAPTER 5
DISCUSSION

5.1 Phenological development

5.1.1 Days to 50% emergence

The mean number of days to 50% emergence between the two cultivars was only significantly different in 2011/2012 season. Inoculation with or without *Rhizobium phaseoli* and its interaction with dry bean cultivars did not have a significant influence on days to 50 % emergence during both growing seasons. Despite the difference in seed size the two cultivars achieved similar speed of germination implying that both had no difficulties in imbibing enough moisture to initiate the germination process. Argaw (2012) also found that co-inoculation with *Bradyrhizobium japonicum* did not have a significant influence on days to emergence in soybean. Therefore, in this present study dry bean emergence was independent of *Rhizobium* inoculation. This is because nitrogen fixation period only starts two to five weeks after bacterial infection (Dupont, *et al*., 2012) and has no bearing on the germination process.

Statistically, results showed that application of phosphorus in this experiment had no significant influence on days to emergence. Khalil *et al*. (2010) also found that phosphorus fertilization did not affect emergence of wheat at the level up to 75 kg P_2O_5 /ha. Lack of response of crop emergence to P application is expected as the applied P has no direct role prior to seedling emergence but could only perhaps affect moisture availability for imbibition by the seed.

5.1.2 Days to 50% flowering

In both growing seasons the red speckled bean reached 50% flowering earlier than the small white haricot. The difference is probably due to genetic differences between the two cultivars. The red speckled was a determinate type 1 while small white haricot was indeterminate type 2. Nchimbi-Msolla and Tryphone (2010) also reported significant differences in the number of days required to reach 50% flowering among 20 common bean genotypes. Earlier attainment of 50% flowering was observed with *Rhizobium* inoculation as compared to the uninoculated treatment. Similar results were found by Zaman *et al.* (2011) who reported early flowering with inoculated plants than uninoculated plants in chickpea.

According to Namvar and Sharifi (2011), *Rhizobium* bacteria synthesize phytohormones such as auxin as secondary metabolites in inoculated plants which play a key role in plant growth promotion or regulation. The results of this study generally showed that days to 50% flowering were reduced in 2011/2012 season as compared to 2012/2013 season. This could have resulted from lack of rainfall at onset of reproductive growth (Figure 4.1), which could have induced early flowering due to drought stress. The effects of water stress have also been observed by Al-Suhaibani, (2009) who reported that water deficit significantly induced early flowering in faba bean.

Days to 50% flowering were not affected by phosphorus fertilization in both growing seasons. Failure to respond to phosphorus application in this experiment might be attributed to high initial P status in the soil prior planting (Table 4.1). According to Liebenberg (2002), P application in dry bean production is recommended when P content of the soil is lower than 20 ppm (Bray 1). In the present study the soil P levels in the 0 -15 cm profile were 32 and 38 mg/kg in the respective seasons.

5.1.3 Days to 50% physiological maturity

Number of days taken by a crop to reach maturity is one of important factors in determining whether a certain cultivar can be successfully grown in particular environment and cropping system. Significant differences ($P \leq 0.05$) were observed on days to physiological maturity between the two cultivars in both growing seasons. The red speckled bean matured early as compared to the small white haricot. Number of days to reach physiological maturity between the two cultivars showed that they were dependent on time required to reach 50% flowering. The difference might also suggest distinction in genetic makeup of the two cultivars. Difference in days to reach maturity in common bean lines had also been reported by Kilasi (2010). Generally, determinate cultivars mature earlier than indeterminate cultivars.

Days taken to reach 50% physiological maturity were extended with uninoculated treatment and the highest growth durations were 97 and 98 days in 2011/2012 and 2012/2013, respectively. The results are supported by Bejandi, *et al.* (2012) who reported that inoculation of seeds with *Rhizobium* reduced days to 70% physiological maturity in chickpea as compared to uninoculated treatment.

In both growing seasons, the number of days to physiological maturity was not affected by P application in this study. These results differs from those of Gidago *et al.* (2011) who found that phosphorus application at 40, 50 and 60 kg P/ ha significantly reduced days to physiological maturity as compared to the control in haricot bean. The non-significant effect of P on phenological development in the present study might be explained by the high levels of P at the experimental sites used in both seasons.

5.2 Nodulation

5.2.1 Number of nodules per plant

Insignificant difference of number of nodules per plant between the two cultivars in 2011/2012 season might be related to low rainfall distribution during that season. Similar results had been reported by Peña-Cabriales and Castellanos (1993) who found reduced number of nodules in different dry bean cultivars due to water stress at both vegetative and reproductive stages. In 2012/2013 planting season the red speckled bean produced higher number of nodules per plant compared to the small white haricot. This indicated considerable variation in nodulation ability between the two cultivars. Comparison of the number of nodules per plant in the two seasons suggest that nodulation in both cultivars is reduced considerably by moisture stress. Hungria and Phillips (1993) reported a reduction in nodule number per plant in a white seeded common bean genotype when compared to a black seeded common bean. These authors found that the levels of anthocyanins which are essential for establishing symbiosis between bean plant and *Rhizobium* were higher in black seeded genotype than in white seeded lines. Gicharu *et al*. (2013) also reported a significant variation in number of nodules among three bush bean cultivars in both greenhouse and field studies inoculated with different rhizobia strains.

Inoculation with *Rhizobium phaseoli* resulted in increased number of nodules per plant compared to uninoculated treatment in both seasons. This might be due to application or introduction of inoculants that increased number of the *Rhizobium* bacteria which infect the roots to form nodules. The higher number of bacteria results in higher number of vigorous nodules per plant. According to ARC-Grain Crop Institute (2010), the number and size of nodules indicate the amount of plant tissue available for nitrogen fixation. Thus, the results of this study also suggest a good

symbiotic association between *Rhizobium phaseoli* and the two dry bean cultivars. These results are in agreement with the findings of Stajković *et al.* (2011), Tagore *et al.* (2013) and Hussain *et al.* (2011), who reported significant increase of number of nodules per plant in inoculated common bean, chickpea and mash bean, respectively. The presence of nodules in uninoculated treatments during both seasons might be the result of existing indigenous soil rhizobium in the soil. Tajini *et al.* (2012) also found that the number of nodules on uninoculated common bean plants was due to low number of native *Rhizobium* which had low potential of infectivity. Table 4.4 shows that there was low number of nodules in 2011/2012 season as compared to 2012/2013 season. This might have been caused by moisture stress due to lack of rain during flowering inception in the first season (Figure 4.1). Mnasri *et al*. (2007) also found that water deficit reduced number of nodules in dry bean. Biological nitrogen fixation is supplied with energy from photosynthesis, hence any stress that affects plant growth affects nodulation and BNF.

Several reports showed that nodulation and nitrogen fixation of most leguminous crops is associated positively with phosphorus fertilization (Bereke and Hailemariam, (2012); Muhammad, (2010); Seresinhe and Pathirana, (2002). Nevertheless, the results of this study demonstrated that P fertilization at different application rates did not affect number of nodules per plant in both growing seasons. These findings are in line with those of Sulieman and Hago (2009) who found that phosphorus application at the rate of up to 200 kg P_2O_5 /ha did not affect number of nodules per plant of common bean. Ojiem *et al.* (2000) also reported non-significant difference on number of nodules per plant of nine legume green manure species in response to P fertilization rates. The available initial P in the top soil during both growing seasons ranged from 30-38 mg/kg. According to the Fertilizer Society of South Africa (2003), the critical levels of P in the soil ranges from 15-30 mg/kg for grain legumes. Thus, application of P in this experiment was not beneficial due to high initial P in the soil.

5.2.2 Nodule dry weight

There were no significant differences observed between the red speckled bean and small white haricot in nodule dry weight during 2011/2012. This could have been due to the low number of nodules in both cultivars associated with low rainfall in that

season. Tajini *et al.* (2012) found a significant decrease in nodule dry mass of two common bean cultivars due to water stress when irrigation was stopped for 20 days in plots subjected to water stress as compared to the control. Statistical analysis showed that during 2012/2013 season the red speckled bean produced more nodule dry weight contrasted to small white haricot. The higher nodule dry weight in red speckled bean could also be linked to its high number of nodules per plant. In this study nodule number and nodule dry weight had significantly positive (0.001) correlation ($R^2 = 0.24$).

Rhizobium inoculation did not have a significant effect on nodule dry weight in 2011/2012 season. The presence of indigenous *Rhizobium* in the soil and low rainfall in 2011/2012 season could have possibly suppressed the activity of introduced commercial inoculants. Mehrpouyan (2011) postulated that native rhizobium strains could be effective in nitrogen fixation in beans and have ability to better compete with non-native bacteria due to their adaptation to the soil conditions. Singleton and Tavares (1986) observed that when available rhizobia were few, individual nodules of uninoculated soybean, peanut, and lima bean plants tended to be larger than the nodules on inoculated plants when large numbers of rhizobia were applied to the roots. Ngeno *et al.* (2012) found decreased nodule dry weight in garden pea genotypes due to moisture stress caused by low rainfall. Deaker *et al.* (2004) further reported that death of rhizobia species on inoculated seed occurs rapidly, particularly when environmental conditions are unfavourable.

Increasing nodule weight by inoculation is a general prerequisite for increasing nitrogen fixation (Singleton and Tavares, 1986). In 2012/2013 season inoculation with *Rhizobium phaseoli* significantly ($P \leq 0.01$) increased nodule dry weight as compared to uninoculated treatments. The increment of nodule dry weight by *Rhizobium* inoculation might be due to higher fixation activity in nodulated plants compared to uninoculated plants coupled with adequate rainfall. Moreover, uninoculated plants had low nodule dry weight, suggesting that indigenous rhizobium had low capacity of infectivity during this season. Increased nodule dry weight with inoculation has been reported by Vargas *et al.* (2000), Bhuiyan *et al.* (2008) and Ahmed (2013) on dry bean, chickpea and soybean, respectively.

Phosphorus fertilization up to the level of 90 kg/ha did not have a significant influence of nodule dry weight during both growing seasons. The results contradict the findings of Asuming-Brempong *et al.* (2013) who noted significant increase in nodule dry weight on cowpea when P is applied at 120 kg P_2O_5/ha. Lack of response to P application on nodule dry weight could again be related to high initial levels of P in the soil.

5.3 Morphological and growth parameters

5.3.1 Number of branches per plant

Number of branches per plant did not differ significantly between the two cultivars in both 2011/2012 and 2012/2013 seasons. Similar results have also been reported by Molatudi and Mariga (2012) who found that non-significant difference in number of branches per plant between the red speckled and small white haricot under different planting densities in maize/dry bean intercropping. Inoculated and non-inoculated plants showed no significant variation in number of branches per plant in both growing seasons. The results are in line with the findings of Karasu *et al*. (2011), who reported that inoculation with *Rhizobium phaseoli* did not have a significant influence on number of branches per plant on three dwarf dry bean cultivars over the period of three years. To the contrary, Namvar *et al*. (2013) found that the greatest number of branches per plant was recorded in inoculated chickpea plants.

Number of branches per plant in response to phosphorus application at different levels was found to be insignificant in both growing seasons. Lack of response to phosphorus application might be related to high initial P in the soil (Table 4.1). Firoz (2009) also reported that phosphorus application at the rate of 80, 100 and 120 kg P_2O_5/ha did not affect percentage of branched plants and number of branches per plant in okra. In general, number of branches per plant was much lower in 2011/2012 season as compared to 2012/2013 season. Low rainfall during 2011/2012 season might have reduced the development of branches in dry bean plants. Karasu *et al*. (2011) related the decreased number of branches in dry beans to excessive drought due to lack of rainfall. Alderfasi and Alghamdi (2010) also found that reduced number branches in soybean were due to shortage of water.

5.3.2 Plant height

The two cultivars did not show any significant differences in plant height during 2011/2012 season. In 2012/2013 season, the red speckled bean was significantly taller than the small white haricot ($P \leq 0.01$) as expected. Inoculation with *Rhizobium phaseoli* did not have a significant effect on plant height in 2011/2012 season, but produced significantly taller plants as compared to uninoculated treatments in the 2012/2013 season. Insignificant differences in 2011/2012 were related to low rainfall which could have resulted in reduced plant growth. Emam *et al.* (2010) also observed reduced plant height of common bean due water stress. The increment of plant height due to *Rhizobium* inoculation might be due to the adequate amount of nitrogen fixed by the bacteria which promoted vegetative growth of the plants. Raza *et al*. (2004) and Sajid *et al*. (2011) also found that *Rhizobium* inoculation increased plant height of mungbean and groundnut, respectively.

In both 2011/2012 and 2012/2013 seasons phosphorus fertilization did not influence plant height. The results are in line with those of Turuko and Mohammed (2014) who indicated that application of P fertilizer has no effect of plant height in common bean. The authors further related the non-significant response to P to the high dose of phosphorus fertilizer which tends to form nutrient interactions which might affects the availability of other nutrients which are essential for growth of the common bean.

5.3.3 Pod length

The red speckled bean produced longer pods in contrast to small white haricot in both growing season. The difference is probably due to genetic makeup of the two cultivars. Dursun (2007) also reported significant difference in pod length among 21 dry bean genotypes. There were no significant differences observed on pod length in response to inoculation. The results contradict the findings of Ravikumar (2012) and Shahid *et al*. (2009) who reported greater pod length from plants inoculated with *Rhizobium* compared to uninoculated plants. However, Tripathi *et al.* (2012) indicated that inoculation with different rhizobial strains did not have a significant influence on pod length of mungbean during two growing seasons.

Statistical analysis revealed that pod length was not significantly affected by phosphorus application in both growing seasons. The results agree with those of

Tunçtürk (2011) who reported non-significant effect of phosphorus doses on pod length over two experimental years in fenugreek. Akhtar *et al*. (2003) on the other hand found that phosphorus application at 69 kg/ha P_2O_5 produced pods with maximum length in pea. Failure to respond to phosphorus fertilization in both growing seasons was probably due to high P in the experimental site.

5.4 Yield components and grain yield

In both growing seasons the red speckled cultivar showed higher values in number of pods per plant, hundred seed weight, grain yield and total above ground biomass as compared to small white haricot. The difference is probably due to the genetic differences between the two cultivars. The red speckled bean is a large seeded cranberry type, whilst small white haricot is small seeded, thus translating to superior hundred seed weight and grain yield in red speckled bean than small white haricot as reported by Molatudi and Mariga (2012) who also found similar results under different planting densities in maize and dry bean intercropping. Tagore *et al.* (2013) also reported that the variation in test weight among the chickpea genotypes is likely to occur due to differences in seed size of the individual genotype which also results in increased grain yield. Number of seed per pod, shelling percentage and harvest index were not significantly different between the two cultivars. These results were in line with those of Molatudi and Mariga (2012) who reported non-significant differences ($P \leq 0.05$) between several yield components of these two dry bean cultivars. From a yield perspective, farmers in the study area can benefit more by growing the red speckled bean. This bean cultivar was reported to outperform the white haricot even under intercropping (Molatudi and Mariga, 2012).

Inoculation with *Rhizobium phaseoli* achieved significant increases in hundred seed weight, grain yield and total above ground biomass compared to uninoculated treatments. This was related to the symbiotic relationship between *Rhizobium phaseoli* and dry bean plants, which results in fixation of atmospheric nitrogen into the roots and translocation of amino acids to the shoots, thus leading to increased yield. Positive effects of bacterial inoculation on yield of various leguminous crops are well documented (Lamptey *et al*., (2014), Albayrak *et al*., (2006), Tairo and Ndakidemi (2013) and Aslam *et al*., (2010). Bambara and Ndakidemi (2010) further reported that the higher yields obtained with inoculation indicates that the *Rhizobium*

technology is efficient in supplying nitrogen to legumes as inorganic nitrogen fertiliser and it is a better option for resource-poor farmer who cannot afford to purchase expensive inputs. However, statistical analysis in both seasons showed that inoculation did not have a significant effect on number of pods per plant, number of seeds per pods, shelling percentage and harvest index. These results are in conformity with those of Abera and Abebe (2014) and Rahman (2006) who reported that inoculation significantly increased grain yield in faba bean and groundnut, respectively but most of the yield attributes were not significantly affected. These results suggest that inclusion of *Rhizobium* inoculation in the production package for dryland production of dry bean in the study area is likely to be cost-effective since the inoculum sachets are fairly affordable.

Despite phosphorus fertilization being an important nutrient supply to increase yields of grain legumes (Kandil *et al*., (2013); Mourice and Tryphone, (2012); Muhammad, (2010); Hashemabadi, (2013), the results of this study showed that P fertilization did not affect grain yield and yield components of dry bean in both 2011/2012 and 2012/2013 growing seasons. These findings were in accordance with those of Sulieman *et al.* (2009) who found that phosphorus application at the rate of up to 200 kg P_2O_5 /ha did not affect plant number per m^2, pod number per plant, seed number per pod, total seed yield, 1000 seed weight and hay yield of common bean. The authors related the lack of response was due to high alkalinity of calcareous soils which results in rapid conversion of applied phosphorus fertilizers into insoluble forms which were not available to the plants. The results of this experiment may suggest response to P fertilization on grain yield and yield components of dry bean, can be realised only on soils with low P. Given the high cost of P fertilizer, farmers should be advised to have their soils tested and only apply P if the soil P status is low.

5.5 Correlation analysis

During 2011/2012 season days to 50% emergence were significantly correlated ($P \leq 0.001$) to number of days to reach 50% flowering and physiological maturity showing that plants which emerged first reached early flowering and physiological maturity. However, in 2012/2013 season days to 50% emergence was not significantly correlated to any of the variables measured. Analysis of correlation in both

2011/2012 and 2012/2013 seasons revealed that days taken to reach 50% flowering were significantly and positively correlated to days to physiological maturity, indicating that dry bean plants which flowered early also reached early physiological maturity. Mulualem *et al*. (2013) and Sidramappa *et al.* (2010) also reported a significant positive correlation between days to flowering and physiological maturity in faba bean and chickpea, respectively. Early maturity is an important cultivar selection criterion in area of short growth season such as the study area.

Both days to 50% flowering and physiological maturity showed to be negatively correlated to the total above ground biomass, number of nodules per plant, nodule dry weight, hundred seed weight, plant height and grain yield. These results suggest that plants which entered late flowering and reproductive stage are likely to have poor biomass, low nodulation and reduced yield. This emphasizes that such results would be useful for cultivar selection within a given environment. The results agree with those of Malik *et al*. (2007).

The observation of positive correlation between grain yield and variables such as number of nodules per plant, nodules dry weight, plant height, number of pods per plant, hundred seed weight and total above ground biomass (Table 4.9 and 4.10) shows that plants which produced more vigorous nodules tend to have high plant growth which results in increased yield components and grain yield. This may also indicate the positive effect of nodulation on growth and yield of dry bean through biological nitrogen fixation. Total above ground biomass is important for soil fertility amelioration if the crop residues are ploughed under. Similar findings were also reported by Bekere *et al.* (2012) and Lamptey *et al.* (2014) who stated that grain yield in dry bean and soybean, respectively is largely dependent on growth traits and yield components. Results from this study suggest that important yield components to monitor in dry bean studies are number of pods per plant, hundred seed weight, grain yield and the total above ground biomass.

CHAPTER 6
SUMMARY AND CONCLUSION

The study showed that commercially viable dry bean yields could be attainable under dry land conditions of Syferkuil. The results of this study strongly indicated that the red speckled bean performs better than the small white haricot. In both 2011/2012 and 2012/2013 seasons the red speckled bean achieved higher plant growth and increased yield relative to the small white haricot. Inoculation with *Rhizobium phaseoli* proved to be beneficial for enhancing dry bean productivity under dryland farming conditions. This technology could thus be used as a cheap external source of plant nutrition especially for smallholder farmers who cannot afford expensive inorganic fertilizers. To better understand the symbiotic relationship between *Rhizobium phaseoli* inoculation and dry bean under similar environments, future studies should be conducted to determine the amount of nitrogen fixed by inoculated dry beans. Detailed monitoring of percentage active nodules and the duration of BNF activity before nodule senescence must be done. Application of phosphorus fertilization at the rate up to 90 kg P/ha did not have an influence on all parameters measured. Failure of dry bean to respond to phosphorus in this experiment was probably due to high initial P status of the soil. Future studies should focus on the response of dry bean in soils with low P. Such studies could also test the effect of inoculation on more bean cultivars under maize/bean intercropping as most dry bean is grown by smallholder farmers under polyculture.

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APPENDICES

Summary of analysis of variance for 2011/2012 season are listed as appendix 8.1 to 8.15.

Appendix 8.1: Analysis of variance (ANOVA) for days to 50% emergence

Source of variation	DF	SS	MS	F	P
Replication	3	20.500	6.833		
Cultivar (C)	1	154.083	154.083	85.34	0.0027
Main plot error	3	5.417	1.806		
Inoculation (I)	1	0.083	0.083	0.06	0.8173
C x I	1	0.333	0.333	0.23	0.6464
Subplot error	6	8.583	1.431		
Phosphorus (P)	2	0.667	0.333	0.12	0.8831
C x P	2	1.167	0.583	0.22	0.8051
I x P	2	2.167	1.083	0.41	0.6706
C x I x P	2	4.667	2.333	0.88	0.4297
Sub-sub plot error	24	64.000	2.667		
Total	47	261.667			

Appendix 8.2: Analysis of variance (ANOVA) for days to 50% flowering

Source of variation	DF	SS	MS	F	P
Replication	3	54.17	18.056		
Cultivar (C)	1	560.33	560.333	18.24	0.0236
Main plot error	3	92.17	30.722		
Inoculation (I)	1	120.33	120.333	16.04	0.0071
C x I	1	65.33	65.333	8.71	0.0256
Subplot error	6	45.00	7.500		
Phosphorus (P)	2	28.04	14.021	1.19	0.3220
C x P	2	2.79	1.396	0.12	0.8889
I x P	2	17.54	8.771	0.74	0.4861
C x I x P	2	35.79	17.896	1.52	0.2397
Sub-sub plot error	24	283.17	11.799		
Total	47	1304.67			

Appendix 8.3: Analysis of variance (ANOVA) for days to 50% physiological maturity

Source of variation	DF	SS	MS	F	P
Replication	3	31.417	10.472		
Cultivar (C)	1	133.333	133.333	23.76	0.0165
Main plot error	3	16.833	5.611		
Inoculation (I)	1	96.333	96.333	15.24	0.0079
C x I	1	36.750	36.750	5.82	0.0525
Subplot error	6	37.917	6.319		
Phosphorus (P)	2	10.792	5.396	1.70	0.2046
C x P	2	0.542	0.271	0.09	0.9186
I x P	2	3.792	1.896	0.60	0.5589
C x I x P	2	3.875	1.937	0.61	0.5520
Sub-sub plot error	24	76.333	3.181		
Total	47	447.917			

Appendix 8.4: Analysis of variance (ANOVA) for number of nodules per plant

Source of variation	DF	SS	MS	F	P
Replication	3	4179.3	1393.09		
Cultivar (C)	1	758.7	758.75	0.48	0.5363
Main plot error	3	4695.1	1565.04		
Inoculation (I)	1	1185.0	1185.05	6.00	0.0498
C x I	1	6.6	6.63	0.03	0.8606
Subplot error	6	1184.1	197.35		
Phosphorus (P)	2	153.5	76.74	0.19	0.8313
C x P	2	1246.2	623.10	1.51	0.2407
I x P	2	706.0	353.00	0.86	0.4371
C x I x P	2	669.3	334.67	0.81	0.4557
Sub-sub plot error	24	9889.2	412.05		
Total	47	24673.1			

Appendix 8.5: Analysis of variance (ANOVA) for nodule dry weight

Source of variation	DF	SS	MS	F	P
Replication	3	0.03516	0.01172		
Cultivar (C)	1	0.02852	0.02852	0.36	0.5892
Main plot error	3	0.23556	0.07852		
Inoculation (I)	1	0.01367	0.01367	0.55	0.4857
C x I	1	0.00200	0.00200	0.08	0.7858
Subplot error	6	0.14868	0.02478		
Phosphorus (P)	2	0.13343	0.06671	1.96	0.1629
C x P	2	0.07924	0.03962	1.16	0.3295
I x P	2	0.00099	0.00049	0.01	0.9856
C x I x P	2	0.05638	0.02819	0.83	0.4492
Sub-sub plot error	24	0.81743	0.03406		
Total	47	1.55105			

Appendix 8.6: Analysis of variance (ANOVA) for number of branches per plant

Source of variation	DF	SS	MS	F	P
Replication	3	6.0590	2.01966		
Cultivar (C)	1	1.4805	1.48052	1.21	0.3523
Main plot error	3	3.6823	1.22744		
Inoculation (I)	1	0.0158	0.01577	0.05	0.8359
C x I	1	0.2745	0.27452	0.81	0.4015
Subplot error	6	2.0212	0.33687		
Phosphorus (P)	2	0.4034	0.20168	0.99	0.3854
C x P	2	0.4083	0.20417	1.00	0.3811
I x P	2	0.1699	0.08493	0.42	0.6631
C x I x P	2	0.2936	0.14680	0.72	0.4959
Sub-sub plot error	24	4.8774	0.20323		
Total	47	19.6859			

Appendix 8.7: Analysis of variance (ANOVA) for plant height

Source of variation	DF	SS	MS	F	P
Replication	3	688.98	229.66		
Cultivar (C)	1	2545.53	2545.53	8.00	0.0663
Main plot error	3	954.87	318.29		
Inoculation (I)	1	8.51	8.51	0.04	0.8565
C x I	1	27.44	27.44	0.11	0.7461
Subplot error	6	1431.97	238.66		
Phosphorus (P)	2	27.19	13.59	0.14	0.8675
C x P	2	154.91	77.46	0.81	0.4545
I x P	2	140.78	70.39	0.74	0.4874
C x I x P	2	344.25	172.12	1.81	0.1851
Sub-sub plot error	24	2281.04	95.04		
Total	47	8605.46			

Appendix 8.8: Analysis of variance (ANOVA) for pod length

Source of variation	DF	SS	MS	F	P
Replication	3	2.9666	0.9889		
Cultivar (C)	1	39.1144	39.1144	18.57	0.0230
Main plot error	3	6.3205	2.1068		
Inoculation (I)	1	0.2930	0.2930	0.12	0.7423
C x I	1	0.0124	0.0124	0.01	0.9459
Subplot error	6	14.8160	2.4693		
Phosphorus (P)	2	0.4157	0.2078	0.19	0.8246
C x P	2	1.8999	0.9500	0.89	0.4244
I x P	2	0.9581	0.4791	0.45	0.6441
C x I x P	2	0.5426	0.2713	0.25	0.7780
Sub-sub plot error	24	25.6622	1.0693		
Total	47	93.0012			

Appendix 8.9: Analysis of variance (ANOVA) for number of pods per plant

Source of variation	DF	SS	MS	F	P
Replication	3	4.070	1.3566		
Cultivar (C)	1	69.721	69.7213	18.54	0.1583
Main plot error	3	16.679	5.5596		
Inoculation (I)	1	60.548	60.5477	154	0.2356
C x I	1	1.364	1.3635	3.60	0.1065
Subplot error	6	2.272	0.3786		
Phosphorus (P)	2	28.604	14.3021	5.11	0.0842
C x P	2	0.045	0.0225	0.01	0.9920
I x P	2	5.033	2.5166	0.90	0.4204
C x I x P	2	0.242	0.1209	0.04	0.9578
Sub-sub plot error	24	67.211	2.8004		
Total	47	255.787			

Appendix 8.10: Analysis of variance (ANOVA) for number of seeds per pod

Source of variation	DF	SS	MS	F	P
Replication	3	1.8651	0.62170		
Cultivar (C)	1	1.0591	1.05910	3.42	0.1614
Main plot error	3	0.9284	0.30946		
Inoculation (I)	1	0.0088	0.00880	0.02	0.9028
C x I	1	0.0567	0.05672	0.10	0.7574
Subplot error	6	3.2538	0.54229		
Phosphorus (P)	2	2.0812	1.04060	4.90	0.1564
C x P	2	0.3826	0.19129	0.90	0.4194
I x P	2	0.2324	0.11619	0.55	0.5856
C x I x P	2	1.2181	0.60904	2.87	0.0764
Sub-sub plot error	24	5.0950	0.21229		
Total	47	16.1811			

Appendix 8.11: Analysis of variance (ANOVA) for hundred seed weight

Source of variation	DF	SS	MS	F	P
Replication	3	125.82	41.94		
Cultivar (C)	1	7727.20	7727.20	658.05	0.0001
Main plot error	3	35.23	11.74		
Inoculation (I)	1	117.69	117.69	14.67	0.0087
C x I	1	73.90	73.90	9.21	0.0230
Subplot error	6	48.15	8.03		
Phosphorus (P)	2	19.73	9.86	0.83	0.4496
C x P	2	0.64	0.32	0.03	0.9736
I x P	2	15.34	7.67	0.64	0.5347
C x I x P	2	6.98	3.49	0.29	0.7492
Sub-sub plot error	24	286.42	11.93		
Total	47	8457.09			

Appendix 8.12: Analysis of variance (ANOVA) for grain yield

Source of variation	DF	SS	MS	F	P
Replication	3	12213	4071		
Cultivar (C)	1	821400	821400	61.18	0.0044
Main plot error	3	40279	13426		
Inoculation (I)	1	623678	623678	7.07	0.0376
C x I	1	87309	87309	0.99	0.3582
Subplot error	6	529166	88194		
Phosphorus (P)	2	48398	24199	0.42	0.6605
C x P	2	25389	12694	0.22	0.8030
I x P	2	370530	185265	3.23	0.0572
C x I x P	2	1930	965	0.02	0.9833
Sub-sub plot error	24	1376010	57334		
Total	47	3936302			

Appendix 8.13: Analysis of variance (ANOVA) for shelling percentage

Source	DF	SS	MS	F	P
Replication	3	16.281	5.4271		
Cultivar (C)	1	4.160	4.1595	0.37	0.5843
Main plot error	3	33.406	11.1353		
Inoculation (I)	1	3.086	3.0856	0.20	0.6738
C x I	1	3.859	3.8590	0.24	0.6385
Subplot error	6	94.640	15.7733		
Phosphorus (P)	2	21.814	10.9069	1.27	0.3003
C x P	2	28.579	14.2895	1.66	0.2116
I x P	2	28.677	14.3383	1.66	0.2106
C x I x P	2	21.456	10.7282	1.24	0.3060
Sub-sub plot error	24	206.857	8.6190		
Total	47	462.813			

Appendix 8.14: Analysis of variance (ANOVA) for harvest index

Source of variation	DF	SS	MS	F	P
Replication	3	0.01642	0.00547		
Cultivar (C)	1	0.08710	0.08710	9.85	0.0567
Main plot error	3	0.02652	0.00884		
Inoculation (I)	1	0.04536	0.04536	4.76	0.0720
C x I	1	0.00138	0.00138	0.14	0.7170
Subplot error	6	0.05722	0.00954		
Phosphorus (P)	2	0.00303	0.00151	0.80	0.4591
C x P	2	0.00571	0.00285	1.52	0.2396
I x P	2	0.00775	0.00388	2.06	0.1493
C x I x P	2	0.00531	0.00266	1.41	0.2630
Sub-sub plot error	24	0.04514	0.00188		
Total	47	0.30094			

Appendix 8.15: Analysis of variance (ANOVA) for total above ground biomass

Source of variation	DF	SS	MS	F	P
Replication	3	153999	51333.0		
Cultivar (C)	1	1.006	1.006	50.99	0.0057
Main plot error	3	592179	197393		
Inoculation (I)	1	224353	224353	0.79	0.4071
C x I	1	300670	300670	1.06	0.3419
Subplot error	6	1694278	282380		
Phosphorus (P)	2	408336	204168	1.09	0.3516
C x P	2	97769.4	48884.7	0.26	0.7721
I x P	2	472100	236050	1.26	0.3011
C x I x P	2	168340	84170.0	0.45	0.6428
Sub-sub plot error	24	4487105	186963		
Total	47	1.866			

Summary of analysis of variance for 2012/2013 season are tabled in Appendix 8.16 to 8.30.

Appendix 8.16: Analysis of variance (ANOVA) for days to 50% emergence

Source of variation	DF	SS	MS	F	P
Replication	3	3.8333	1.27778		
Cultivar (C)	1	2.0833	2.08333	0.84	0.4263
Main plot error	3	7.4167	2.47222		
Inoculation (I)	1	1.3333	1.33333	0.69	0.4378
C x I	1	0.0833	0.08333	0.04	0.8423
Subplot error	6	11.5833	1.93056		
Phosphorus (P)	2	1.6250	0.81250	0.50	0.6140
C x P	2	5.0417	2.52083	1.54	0.2339
I x P	2	5.5417	2.77083	1.70	0.2043
C x I x P	2	3.2917	1.64583	1.01	0.3797
Sub-sub plot error	24	39.1667	1.63194		
Total	47	81.0000			

Appendix 8.17: Analysis of variance (ANOVA) for days to 50% flowering

Source of variation	DF	SS	MS	F	P
Replication	3	24.417	8.139		
Cultivar (C)	1	208.333	208.333	17.61	0.0247
Main plot error	3	35.500	11.833		
Inoculation (I)	1	96.333	96.333	6.52	0.0432
C x I	1	10.083	10.083	0.68	0.4402
Subplot error	6	88.583	14.764		
Phosphorus (P)	2	3.167	1.583	0.19	0.8258
C x P	2	20.667	10.333	1.26	0.3021
I x P	2	11.167	5.583	0.68	0.5160
C x I x P	2	12.667	6.333	0.77	0.4734
Sub-sub plot error	24	197.000	8.208		
Total	47	707.917			

Appendix 8.18: Analysis of variance (ANOVA) for days to 50% physiological maturity

Source of variation	DF	SS	MS	F	P
Replication	3	8.833	2.9444		
Cultivar (C)	1	33.333	33.3333	10.91	0.0456
Main plot error	3	9.167	3.0556		
Inoculation (I)	1	56.333	56.3333	14.70	0.0086
C x I	1	21.333	21.3333	5.57	0.0564
Subplot error	6	23.000	3.8333		
Phosphorus (P)	2	1.625	0.8125	0.26	0.7705
C x P	2	1.292	0.6458	0.21	0.8125
I x P	2	1.292	0.6458	0.21	0.8125
C x I x P	2	5.792	2.8958	0.94	0.4048
Sub-sub plot error	24	74.000	3.0833		
Total	47	236.000			

Appendix 8.19: Analysis of variance (ANOVA) for number of nodules per plant

Source of variation	DF	SS	MS	F	P
Replication	3	1745.8	581.93		
Cultivar (C)	1	3699.5	3699.54	40.07	0.0080
Main plot error	3	277.0	92.32		
Inoculation (I)	1	2772.5	2772.48	12.97	0.0114
C x I	1	9.0	9.01	0.04	0.8441
Subplot error	6	1282.9	213.81		
Phosphorus (P)	2	913.7	456.87	2.46	0.1071
C x P	2	288.5	144.25	0.78	0.4718
I x P	2	194.0	97.02	0.52	0.6002
C x I x P	2	135.6	67.81	0.36	0.6983
Sub-sub plot error	24	4465.6	186.07		
Total	47	15784.2			

Appendix 8.20: Analysis of variance (ANOVA) for nodule dry weight

Source of variation	DF	SS	MS	F	P
Replication	3	0.31862	0.10621		
Cultivar (C)	1	1.05317	1.05317	17.40	0.0251
Main plot error	3	0.18157	0.06052		
Inoculation (I)	1	0.63710	0.63710	13.95	0.0097
C x I	1	0.00880	0.00880	0.19	0.6761
Subplot error	6	0.27408	0.04568		
Phosphorus (P)	2	0.24135	0.12068	2.55	0.0988
C x P	2	0.03789	0.01894	0.40	0.6742
I x P	2	0.04020	0.02010	0.43	0.6584
C x I x P	2	0.22480	0.11240	2.38	0.1142
Sub-sub plot error	24	1.13435	0.04726		
Total	47	4.15195			

Appendix 8.21: Analysis of variance for (ANOVA) number of branches per plant

Source of variation	DF	SS	MS	F	P
Replication	3	3.7331	1.24436		
Cultivar (C)	1	1.0951	1.09505	0.90	0.4127
Main plot error	3	3.6497	1.21658		
Inoculation (I)	1	0.9492	0.94922	1.49	0.2685
C x I	1	2.8763	2.87630	4.51	0.0780
Subplot error	6	3.8307	0.63845		
Phosphorus (P)	2	0.6979	0.34896	0.71	0.5010
C x P	2	0.2917	0.14583	0.30	0.7455
I x P	2	3.8750	1.93750	3.95	0.0329
C x I x P	2	0.3229	0.16146	0.33	0.7227
Sub-sub plot error	24	11.7708	0.49045		
Total	47	33.0924			

Appendix 8.22: Analysis of variance (ANOVA) for plant height

Source of variation	DF	SS	MS	F	P
Replication	3	393.37	131.12		
Cultivar (C)	1	4450.79	4450.79	58.69	0.0046
Main plot error	3	227.49	75.83		
Inoculation (I)	1	1063.42	1063.42	18.35	0.0052
C x I	1	3.48	3.48	0.06	0.8145
Subplot error	6	347.76	57.96		
Phosphorus (P)	2	28.08	14.04	0.24	0.7891
C x P	2	100.50	50.25	0.86	0.4372
I x P	2	212.48	106.24	1.81	0.1852
C x I x P	2	172.86	86.43	1.47	0.2492
Sub-sub plot error	24	1408.08	58.67		
Total	47	8408.32			

Appendix 8.23: Analysis of variance (ANOVA) for pod length

Source of variation	DF	SS	MS	F	P
Replication	3	1.6199	0.5400		
Cultivar (C)	1	72.9640	72.9640	235.57	0.0006
Main plot error	3	0.9292	0.3097		
Inoculation (I)	1	0.3267	0.3267	0.51	0.5011
C x I	1	0.2945	0.2945	0.46	0.5221
Subplot error	6	3.8272	0.6379		
Phosphorus (P)	2	1.7329	0.8665	1.63	0.2176
C x P	2	0.7043	0.3521	0.66	0.5256
I x P	2	1.1669	0.5834	1.09	0.3507
C x I x P	2	0.4003	0.2001	0.38	0.6908
Sub-sub plot error	24	12.7881	0.5328		
Total	47	96.7540			

Appendix 8.24: Analysis of variance (ANOVA) for number of pods per plant

Source of variation	DF	SS	MS	F	P
Replication	3	3.743	1.248		
Cultivar (C)	1	122.720	122.720	6.60	0.0825
Main plot error	3	55.775	18.592		
Inoculation (I)	1	0.006	0.006	0.00	0.9870
C x I	1	1.188	1.188	0.05	0.8232
Subplot error	6	130.807	21.801		
Phosphorus (P)	2	31.090	15.545	1.91	0.1701
C x P	2	11.751	5.875	0.72	0.4963
I x P	2	49.556	24.778	3.04	0.0664
C x I x P	2	1.519	0.759	0.09	0.9113
Sub-sub plot error	24	195.432	8.143		
Total	47	603.587			

Appendix 8.25: Analysis of variance (ANOVA) for number of seeds per pod

Source OF variation	DF	SS	MS	F	P
Replication	3	78.24	26.081		
Cultivar (C)	1	217.26	217.260	6.81	0.0797
Main plot error	3	95.75	31.916		
Inoculation (I)	1	7.62	7.616	0.36	0.5685
C x I	1	82.58	82.583	3.94	0.0942
Subplot error	6	125.62	20.936		
Phosphorus (P)	2	11.12	5.559	0.20	0.8212
C x P	2	36.80	18.399	0.66	0.5274
I x P	2	68.85	34.426	1.23	0.3102
C x I x P	2	2.63	1.313	0.05	0.9543
Sub-sub plot error	24	671.92	27.997		
Total	47	1398.37			

Appendix 8.26: Analysis of variance (ANOVA) for hundred seed weight

Source of variation	DF	SS	MS	F	P
Replication	3	139.02	46.34		
Cultivar (C)	1	5823.19	5823.19	208.60	0.0007
Main plot error	3	83.75	27.92		
Inoculation (I)	1	0.19	0.19	0.01	0.9314
C x I	1	5.49	5.49	0.23	0.6476
Subplot error	6	142.37	23.73		
Phosphorus (P)	2	3.28	1.64	0.13	0.8752
C x P	2	11.42	5.71	0.47	0.6330
I x P	2	14.58	7.29	0.60	0.5594
C x I x P	2	13.20	6.60	0.54	0.5903
Sub-sub plot error	24	293.89	12.25		
Total	47	6530.38			

Appendix 8.27: Analysis of variance (ANOVA) for grain yield

Source of variation	DF	SS	MS	F	P
Replication	3	980840	326947		
Cultivar (C)	1	6755048	6755048	415.10	0.0003
Main plot error	3	48819.9	16273		
Inoculation (I)	1	3307306	3307306	13.28	0.0108
C x I	1	63827.6	63828	0.26	0.6308
Subplot error	6	1494647	249108		
Phosphorus (P)	2	68424.9	34212	0.16	0.8567
C x P	2	1308724	654362	2.98	0.0700
I x P	2	643845	321923	1.46	0.2511
C x I x P	2	378584	189292	0.86	0.4353
Sub-sub plot error	24	5274907	219788		
Total	47	2.032			

Appendix 8.28: Analysis of variance (ANOVA) for shelling percentage

Source of variation	DF	SS	MS	F	P
Replication	3	2.72896	0.9097		
Cultivar (C)	1	30.4327	30.4327	3.11	0.1760
Main plot error	3	29.3553	9.7851		
Inoculation (I)	1	1.56241	1.5624	0.11	0.7498
C x I	1	2.083	0.0002	0.00	0.9970
Subplot error	6	84.0843	14.0140		
Phosphorus (P)	2	31.2183	15.6092	2.28	0.1243
C x P	2	8.54540	4.2727	0.62	0.5446
I x P	2	2.07702	1.0385	0.15	0.8602
C x I x P	2	32.7150	16.3575	2.39	0.1134
Sub-sub plot error	24	164.497	6.8541		
Total	47	387.217			

Appendix 8.29: Analysis of variance (ANOVA) for harvest index

Source of variation	DF	SS	MS	F	P
Replication	3	0.04376	0.01459		
Cultivar (C)	1	0.03860	0.03860	3.02	0.1809
Main plot error	3	0.03841	0.01280		
Inoculation (I)	1	0.02750	0.02750	3.48	0.1116
C x I	1	0.00053	0.00053	0.07	0.8043
Subplot error	6	0.04748	0.00791		
Phosphorus (P)	2	0.01886	0.00943	1.14	0.3377
C x P	2	0.04205	0.02103	2.53	0.1004
I x P	2	0.01047	0.00524	0.63	0.5408
C x I x P	2	0.02751	0.01375	1.66	0.2118
Sub-sub plot error	24	0.19923	0.00830		
Total	47	0.49441			

Appendix 8.30: Analysis of variance (ANOVA) for total above ground biomass

Source of variation	DF	SS	MS	F	P
Replication	3	4368052	1456017		
Cultivar (C)	1	8961512	8961512	11.99	0.0405
Main plot error	3	2241435	747145		
Inoculation (I)	1	3870500	3870500	12.37	0.0126
C x I	1	152693	152693	0.49	0.5110
Subplot error	6	1877190	312865		
Phosphorus (P)	2	1157736	578868	2.53	0.1006
C x P	2	455864	227932	1.00	0.3839
I x P	2	653976	326988	1.43	0.2590
C x I x P	2	12542.5	6271	0.03	0.9730
Sub-sub plot error	24	5489032	228710		
Total	47	2.924			