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Full Length Article

Influence of *Rhizobium phaseoli* Inoculation and Phosphorus Application on Nodulation and Yield of two Dry Bean (*Phaseolus vulgaris*) Cultivars

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Abstract

Two field experiments were conducted to investigate the response of dry bean cultivars to inoculation and phosphorus application under dryland farming conditions during two summer growing seasons at the Syferkuil farm of University of Limpopo. The experiments were split split-plot arrangements in randomized complete block design with four replications. The main plot factor comprised of 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. There was no interactive effect of treatment factors on nodulation and most yield parameters. In 2011/2012 growing season nodulation was not significantly different between the two cultivars, but in 2012/2013 season the red speckled bean achieved significantly higher number of nodules per plant and nodule dry weight. Inoculation with *R. phaseoli* resulted in increased nodulation in 2012/2013 season. Cultivar significantly affected 100 seed weight, grain yield and total above ground biomass in both growing seasons. The red speckled bean produced higher grain yield of 1657 kg/ha and 2547 kg/ha 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 ($P \leq 0.05$) influence on all parameters measured in the experiment during both growing seasons.

Keywords: Cultivar; *Rhizobium*; Inoculation; Phosphorus; Nodulation

Introduction

Dry bean (*Phaseolus vulgaris*) is the most widely cultivated species of *Phaseolus* in terms of tonnes of crop produced per year and the second most important leguminous crop in the world after soybean (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). Despite these benefits, the level of production of dry bean does not meet local demand hence South Africa imports dry beans to an average value of about US$ 10.5 million per annum mainly from Asia, America and Europe, with minimum imports from Africa (DAFF, 2012). Production by small scale farmers is low and mainly for subsistence (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 show 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) 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; Ditta *et al*., 2015), especially in the smallholder farming sector. Smallholder farmers also do not apply inoculants to their grain legumes.

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. Kgonyane *et al*. (2013) reported low soil P which were predominately in the 1 to 4 mg/kg range

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in Limpopo province of South Africa in the area of the current study. In the current study, both phosphorus fertilizer and inoculation were applied to determine the nodulation and yield of dry bean under dryland farming conditions in Limpopo province where majority of smallholder farmers depend solely on erratic rainfall which ranges between 400 to 495 mm per annum.

Materials and Methods

Study Site

Two experiments were conducted at Syferkuil farm of the University of Limpopo (23◦ 59' 35" S, 29◦ 33' 46" E) during 2011/2012 and 2012/2013 growing seasons. The soil and climatic conditions of the study location are presented in Table 1; Fig. 1 and 2, respectively.

Experimental Design and Treatments

The field experiments were arranged as split split-plots in a Randomized Complete Block Design 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 measured 3 m × 3.6 m with six rows at inter and intra row spacings of 0.6 m and 0.15 m, respectively.

Experimental Procedure

Dry bean seed of the inoculation treatment was 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. 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 irrigation applied was always below the long-term rainfall average of each month. The experiments were kept weed free throughout the growing seasons and were sprayed with Malathion 50% emulsifiable concentrate (E.C.) to control insect pests.

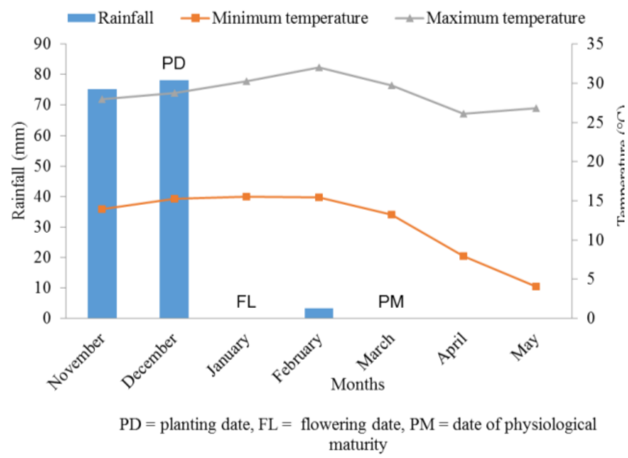

Fig. 1: Monthly average rainfall, minimum and maximum temperatures at Syferkuil farm in 2011/2012 growing season

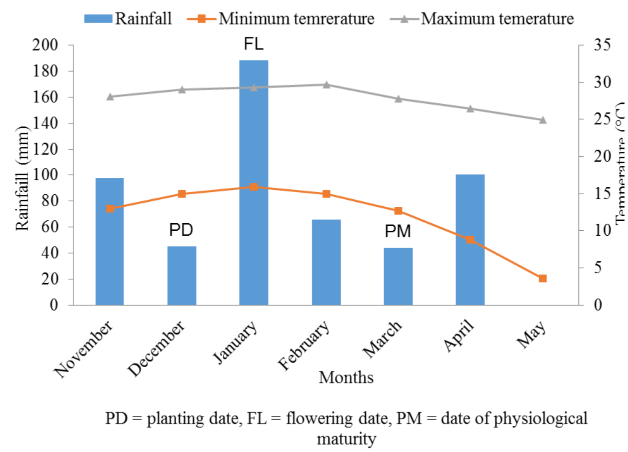

Fig. 2: Monthly average rainfall, minimum and maximum temperatures at Syferkuil farm in 2012/2013 growing season

Data Collection

At 50% flowering, five representative plants from each net plot where dug and separated into roots and shoots. The roots were carefully washed with tap 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 h 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 an electronic weighing balance 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 by Singh and Oswalt (1995):

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

Statistical Analysis

The data were subjected to analysis of variance using general linear model of analytical software Statistix 9.0 (2008) (Tallahassee, Florida. USA), while the mean separation for treatments was done using the Tukey's Honestly Significant Difference (HSD) at 5% level.

Results

Root Nodulation

Nodulation was not influenced by the interactive effects between cultivar × inoculation, cultivar × phosphorus, inoculation × phosphorus, and cultivar × inoculation × phosphorus in both 2011/2012 and 2012/2013 growing seasons (Tables 2 and 3). There were no significant ($P \leq 0.05$) differences observed in number of nodules per plant and nodule dry weight between the two cultivars in 2011/2012 season (Table 4). In 2012/2013 planting season the red speckled bean produced higher number of nodules per plant and nodule dry weight compared to the small white haricot (Table 4). Numbers of nodules per plant and nodule dry weight were approximately 47.04 and 71.43% higher in red speckled bean, than in small white haricot, respectively. Nodule number and dry weight were higher in the second season for both dry bean cultivars (Table 4). Inoculation with *R. phaseoli* resulted in increased number of nodules per plant compared to uninoculated treatment in both seasons (Table 4). Lower values of 21.0 and 38.5 number of nodules per plant were observed with uninoculated treatment in respective seasons. Inoculation with *R. phaseoli* did not significantly ($P \leq 0.05$) 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 in 2012/2013 season (Table 4). Both number of nodules and nodule dry weight were not affected by phosphorus fertilization in both growing seasons at $P \leq 0.05$ (Tables 2 and 3).

Grain Yield and Yield Components

Tables 5 and 6 show the main effect of cultivar and inoculation on yield components of dry bean during both 2011/2012 and 2012/2013 growing seasons. Cultivar significantly affected hundred seed weight, grain yield and total above ground biomass in both growing seasons. In 2011/2012 season the red speckled bean produced about 15.1 pods per plant, whilst small white haricot had 12.6 pods per plant (Table 5). Hundred seed weight, grain yield and total above ground biomass of the red speckled bean in 2011/2012 season were approximately 128.79, 18.69 and 38.17%, respectively higher than of values for small white haricot at $P \leq 0.01$. 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 during 2012/2013 growing season. The total above ground biomass of the red speckled bean was approximately 27.75% higher than that of small white haricot at a P value of ≤ 0.05 (Table 6). Number of seeds per pod, shelling percentage and harvest index were not significantly ($P \leq 0.05$) different between the two cultivars in both 2011/2012 and 2012/2013 seasons (Table 2 and 3).

The interaction between cultivar and inoculation significantly ($P \leq 0.05$) affected hundred seed weight in 2011/2012 season (Table 2). There was no other interactive effect of treatment factors on grain yield and yield components in both growing seasons (Tables 2 and 3). In 2011/2012 season inoculation with *R. 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 *R. phaseoli* inoculation. The total above ground biomass was not significantly influenced by inoculation in the 2011/2012 season (Table 5). During 2012/2013 season, there was no significant influence of *R. phaseoli* inoculation on hundred seed weight (Table 6). However, high grain yield of 2434 kg/ha and total above ground biomass of 3830 kg/ha ($P \leq 0.01$) in 2012/2013 season 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 application at varying rates did not have any significant effect on all yield parameters measured during both 2011/2012 and 2012/2013 seasons (Table 2 and 3).

Discussion

Insignificant differences of number of nodules per plant and nodule dry weight between the two cultivars in 2011/2012 season might be related to low rainfall distribution during that season (Fig. 1). 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 and nodule dry weight compared to the small white haricot. This indicated considerable variation in nodulation ability between the two cultivars. Hungria and Phillips (1993) reported a reduction

Table 1: Chemical soil analysis prior to planting and at harvest

Time of harvest	Depths (cm)	2011/2012 season						
		Parameters						
		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 (cm)	Parameters						
		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

Table 2: Analysis of variance showing the effect cultivar, inoculation and phosphorus on nodulation and yield components of dry bean in 2011/2012 growing season

Source of variation	DF	Mean square Number of nodules	Nodule dry weight (g/plant)	Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg/ha)	Shelling percentage	Harvest index	Total above ground biomass (kg/ha)
Replication	3	1393.09	0.01172	1.3566	0.62170	41.94	4071	5.4271	0.00547	51333.0
Cultivar (C)	1	758.75 ns	0.02852 ns	69.7213 *	1.05910 ns	7727.2 **	821400 **	4.1595 ns	0.08710 ns	1.006 **
Main plot error	3	1565.04	0.07852	5.5596	0.30946	11.74	13426	11.1353	0.00884	197393
Inoculation (I)	1	1185.05 *	0.01367 ns	60.5477 ns	0.00880 ns	117.69 **	623678 **	3.0856 ns	0.04536 ns	224353 ns
C × I	1	0.00200 ns	1.3635 ns	0.05672 ns	73.90 *		87309 ns	3.8590 ns	0.00138 ns	300670 ns
Subplot error	6	197.35	0.02478	0.3786	0.54229	8.03	88194	15.7733	0.00954	282380
Phosphorus (P)	2	76.74 ns	0.06671 ns	14.3021 ns	1.04060 ns	9.86 ns	24199 ns	10.9069 ns	0.00151 ns	204168 ns
C × P	2	623.10 ns	0.03962 ns	0.0225 ns	0.19129 ns	0.32 ns	12694 ns	14.2895 ns	0.00285 ns	48884.7 ns
I × P	2	353.00 ns	0.00049 ns	2.5166 ns	0.11619 ns	7.67 ns	185265 ns	14.3383 ns	0.00388 ns	236050 ns
C × I × P	2	334.67 ns	0.02819 ns	0.1209 ns	0.60904 ns	3.49 ns	965 ns	10.7282 ns	0.00266 ns	84170.0 ns
Sub-sub plot error	24	412.05	0.03406	2.8004	0.21229	11.93	57334	8.6190	0.00188	186963
Total	47									

* = significant ($P \leq 0.05$), ** = significant ($P \leq 0.01$), ns = non-significant ($P \leq 0.05$)

Table 3: Analysis of variance showing the effect cultivar, inoculation and phosphorus on nodulation and yield components of dry bean in 2012/2013 growing season

Source of variation	DF	Mean square Number of nodules	Nodule dry weight (g/plant)	Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg/ha)	Shelling percentage	Harvest index	Total above ground biomass (kg/ha)
Replication	3	581.93	0.10621	1.248	26.081	46.34	326947	0.9097	0.01459	1456017
Cultivar (C)	1	3699.54 **	1.05317 *	122.72 ns	217.26 ns	5823.19 **	6755048 **	30.4327 ns	0.03860 ns	8961512 *
Main plot error	3	92.32	0.06052	18.592	31.916	27.92	16273	9.7851	0.01280	747145
Inoculation (I)	1	2772.48 **	0.63710 **	0.006 ns	7.616 ns	0.19 ns	3307306 **	1.5624 ns	0.02750 ns	3870500 **
C × I	1	9.01 ns	0.00880 ns	1.188 ns	82.583 ns	5.49 ns	63828 ns	0.0002 ns	0.00053 ns	152693 ns
Subplot error	6	213.81	0.04568	21.801	20.936	23.73	249108	14.0140	0.00791	312865
Phosphorus (P)	2	456.87 ns	0.12068 ns	15.545 ns	5.559 ns	1.64 ns	34212 ns	15.6092 ns	0.00943 ns	578868 ns
C × P	2	144.25 ns	0.01894 ns	5.875 ns	18.399 ns	5.71 ns	654362 ns	4.2727 ns	0.02103 ns	227932 ns
I × P	2	97.02 ns	0.02010 ns	24.778 ns	34.426 ns	7.29 ns	321923 ns	1.0385 ns	0.00524 ns	326988 ns
C × I × P	2	67.81 ns	0.11240 ns	0.759 ns	1.313 ns	6.60 ns	189292 ns	16.3575 ns	0.01375 ns	6271 ns
Sub-sub plot error	24	186.07	0.04726	8.143	27.997	12.25	219788	6.8541	0.00830	228710
Total	47									

* = significant ($P \leq 0.05$), ** = significant ($P \leq 0.01$), ns = non-significant ($P \leq 0.05$)

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.

Number of nodules per plant was increased with R. *phaseoli* inoculation during both growing seasons (Table 4). This might be due to application or introduction of

Table 4: Nodulation of dry bean as affected by cultivar and inoculation during 2011/2012 and 2012/2013 growing seasons

Treatments	2011/2012 season		2012/2013 season	
	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 $_{0.05}$	—	—	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 $_{0.05}$	9.92	—	10.33	0.15

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 ($P \leq 0.05$)

Table 5: Main effect of cultivar and inoculation on number of pods per plant, hundred seed weight, grain yield and total above ground biomass in 2011/2012 growing season

Treatments	Number of pods per plant	Hundred seed weight (g)	Grain yield (kg/ha)	Total above ground biomass (kg/ha)
Cultivar				
Red speckled	15.1a	45.3a	1657a	3316a
Small white haricot	12. 6b	19.8b	1396b	2400b
Significant	*	**	**	**
Tukey's HSD $_{0.05}$	2.32	3.15	106.46	408.22
Inoculation				
Inoculated	13.8a	34.1a	1640a	2926a
Uninoculated	13.8a	31.0b	1412b	2789a
Significant	ns	**	*	ns
Tukey's HSD $_{0.05}$	—	2.00	209.79	—

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 6: Main effect of cultivar and inoculation on hundred seed weight, grain yield and total above ground biomass in 2012/2013 growing season

Treatments	Hundred seed weight (g)	Grain yield (kg/ha)	Total above ground biomass (kg/ha)
Cultivar			
Red speckled	48.3a	2547a	3979a
Small white haricot	26.2b	1797b	3114b
Significant	**	**	*
Tukey's HSD $0_{.05}$	4.85	117.21	794.20
Inoculation			
Inoculated	37.3a	2434a	3830a
Uninoculated	37.2a	1909b	3263b
Significant	ns	**	**
Tukey's HSD $_{0.05}$	—	352.58	395.14

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 ($P \leq 0.05$)

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 *R. phaseoli* and the two dry bean cultivars. Tagore *et al.* (2013) earlier reported significant increase of number of nodules per plant of common bean, chickpea and mash bean by inoculation.

The presence of nodules in uninoculated treatments during both seasons might be the result of existing indigenous soil rhizobia 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 shows that there was low number of nodules and nodule dry weight 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 (Fig. 1). Mnasri *et al.* (2007) also found that water deficit reduced number of nodules in dry bean, whist Tajini *et al.* (2012) reported 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. 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 (Muhammad, 2010; Bereke and Hailemariam, 2012). Nevertheless, the results of this study demonstrated that P fertilization at different application rates did not affect nodulation in both growing seasons (Tables 2 and 3). Failure to respond to phosphorus application in this experiment might be attributed to high initial P status in the soil prior to planting (Table 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. Thus, application of P in this experiment could not have been beneficial due to high initial P in the soil.

In respective 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 of 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 variation in grain yield. Number of seeds per pod, shelling percentage and harvest index were not significantly ($P \leq 0.05$) different between the two cultivars in both 2011/2012 and 2012/2013 seasons (Table 2 and 3). These results are 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 *R. phaseoli* achieved significant increases in hundred seed weight, grain yield and total above ground biomass compared to uninoculated treatments. This may be related to the symbiotic relationship between *R. 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 Albayrak *et al*. (2006), Tairo and Ndakidemi (2013); Aslam *et al.* (2010). Bambara and Ndakidemi (2010) further reported that the higher yields obtained with inoculation indicate that the *Rhizobium* technology is efficient in supplying nitrogen to legumes as inorganic nitrogen fertiliser and it is a better option for the 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 pod, shelling percentage and harvest index (Tables 2 and 3). These results are in conformity with those of Abera and Abebe (2014); 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.

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 (Tables 2 and 3). The results contradict the findings of Kandil *et al*. (2013); Mourice and Tryphone (2012); Muhammad (2010); Hashemabadi (2013) but agree 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 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. Lack of response to P application could again be related to high initial levels of P in the soil. The results of this experiment may suggest that 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.

Conclusion

The study showed that commercially viable dry bean yields could be attainable under dryland conditions of Syferkuil. The results of this study strongly indicated that the red speckled bean performs better than the small white haricot. In both growing seasons the red speckled bean achieved higher nodulation and increased yield relative to the small white haricot. Inoculation with *R. 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 *R. 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 percent active nodules and the duration of BNF activity before nodule senescence must also 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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