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Effects of *Rhizobium* inoculation and cropping systems on macronutrients uptake and partitioning in two legumes (Common bean and Lablab)

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ABSTRACT

The study to investigate the effect of *Rhizobium* inoculation and cropping systems on the uptake of macronutrients in shoot, root and whole plant of *Phaseolus vulgaris and Lablab purpureus* was conducted at Selian Agricultural Research Institute (SARI) for two cropping seasons. A randomized complete block design was used in a 3-factorial arrangement with two levels of *Rhizobium* (with and without rhizobia), two legumes (*P. vulgaris* and *L. purpureus*) and five cropping systems (sole maize or sole legumes, 1 row maize to 1 row legumes (1:1) i.e. 0 m or 0.45 m of legume from maize row, 1 row maize to 2 rows of legumes (1:2) i.e. 0.1 m or 0.2 m of legumes from maize rows). The result showed that *Rhizobium* inoculation significantly ($P \leq 0.001$) increased the uptake of N, P, K, Ca and Mg in the plant parts and whole plant. Similarly, cropping systems significantly ($P \leq 0.001$) increased the uptake of N, K and Mg in shoots and whole plant of *P. vulgaris* and *L. purpureus* but decreased the P and Ca content in roots. Legumes significantly increased the uptake of the macronutrients in shoots and roots but more nutrients concentration in shoots than roots for both cropping seasons. There were significant ($P \leq 0.001$) interaction between; *Rhizobium* x legumes x cropping systems on whole plant uptake of N in cropping season 1 and 2. Regardless of the type of interaction, inoculated legumes maximized the uptake of macronutrients in shoots, roots and whole plant.

Key words: Soil nutrients, Biofertilizers, Mineral elements, Rhizosphere, Microorganisms.

INTRODUCTION

Agricultural production has decreased around 35% and it is expected to decrease more with alarming pace (Tayyab *et al.,* 2016). Poor practices and land miss-managements due to over cultivation and overgrazing are the main causes to soil degradation (Tayyab *et al.,* 2015). However, in recent years, agricultural experts have developed interest in application of biofertilizers in cereal-legumes intercrop to enhance soil's physical, chemical and biological characteristics (Shabani *et al.,* 2015). Also Shabani *et al.* (2015) reported that the use of mutualistic plant-fungus symbiosis, phosphate solubilising microorganisms, and vermicompost has long been recognized as beneficial for plant growth and the maintenance of soil fertility in cereal-legumes production. Soil microorganisms such as rhizobacteria are reported to influence the chemistry of soils in many ways and enhance nutrients uptake by plants in the soil rhizosphere (Saharan *et al.,* 2011). Makoi *et al.* (2013) reported that rhizobia inoculation significantly increased the uptake of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) in *P. vulgaris* parts and attributed the improved uptake to increased soil pH which favored the availability of most mineral elements.

In different cropping systems involving legumes species particularly *P. vulgaris* and *L. purpureus* legumes assist in the recycling of these nutrients and in bringing them up from the deeper soil layers (Snapp *et al.,* 1998). These legumes thus serve a dual role, in promoting deep uptake of nutrients making them readily available for the other crops as well as influencing the soil aggregation. Legumes are more efficient at the uptake of P, K, Ca and Mg and have proved to cause severe competition for the cereal crops (Mmbaga *et al.,* 2014). If the species have different rooting and uptake patterns, such as cereal/legume intercropping system, more efficient use of available nutrients may occur (Matusso *et al.,* 2014). Spatial nutrient uptake can be increased through the increasing root mass, while temporal advantages in nutrient uptake occur when crops in an intercropping system have peak nutrient demands at different times (Matusso *et al.,* 2014). Intercropping may also accelerate soil nutrient depletion, particularly for phosphorous, due to more efficient use of soil nutrients. Dahmardeh *et al.* (2010) reported that maize-cowpea intercropping increases the amount of N, P and K contents compared with monocrops of maize which are essential mineral elements present in relatively large amounts in plant tissues. Their uptake by plants depends

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largely on the amount, concentration and activities in the rhizosphere as well as the capacity of the soil to replenish them in the soil solution (Christoph *et al.,* 2008). On other hand, the essential macronutrients uptake are declining due to diverse factors including continuous cropping without additional inputs in the soil, acidification, leaching and soil erosion (Christoph *et al.,* 2008; Achieng and Odhiambo, 2013) causing a huge yield reduction of the crops.

Despite the research done on the macronutrient uptake by legume plants, the use of *Rhizobium* inoculation is very minimal under the areas of legumes production. Also there is still little information about the role that is played by rhizobia inoculants in cereal-legumes intercrop on the availability of other nutrients in legume crops. Based on these facts, it is therefore important to establish the possible role which could be played by *Rhizobium* inoculants and the intercropping practice on the availability of macronutrient in legumes such as common bean and lablab.

MATERIALS AND METHODS

Description of the research experimental site: Two field experiments were conducted at Selian Agricultural Research Institute (SARI) farm in northern part of Tanzania (April to September 2015 and October 2015 to February 2016 cropping seasons). SARI lies at Latitude 3°21'50.08"N and Longitude 36°38'06.29"E at an elevation of 1390 m a s l with mean annual rainfall of 870mm. The mean maximum and minimum temperature ranges from 22ºC to 28ºC and 12ºC to 15ºC respectively. The soil characterization of the site had previously reported by Massawe *et al.* (2016).

Experimental design and planting: Land preparation involved clearing, ploughing, layout and finally planting. The experimental design followed a randomized complete block design (RCBD) in a 3-factorial arrangement with 4 replications per treatment. The experimental treatments consisted of 2 levels of *Rhizobium* inoculation (with and without *Rhizobium*), 2 legumes (*P. vulgaris* and *L. purpureus*) and 5 cropping systems (sole maize or sole legumes, 1 row maize to 1 row legumes (1:1) i.e. 0 m or 0.45 m of legume from maize row, 1 row maize to 2 rows of legumes (1:2) i.e. 0.1 m or 0.2 m of legumes from maize rows). The field plots measured 4 m × 4 m with 5 rows of maize spaced at (0.9 m x 0.5 m) apart and 8 rows of legumes spaced at (0.5 m × 0.2 m). The plots were interspaced by 1 m to allow management of crops.

The BIOFIX legume inoculants were obtained from *MEA* Company Nairobi-Kenya, sold under license from the University of Nairobi. Maize variety (SEEDCO 503) was obtained from SEEDCO Seed Company in Arusha and Common bean seeds variety (Lyamungo 90) and Lablab variety (Rongai) were obtained from Selian

Agricultural Research Institute-Arusha-Tanzania. Before sowing, the legume seeds were thoroughly mixed with *Rhizobium* inoculants to supply (10^9cells/gseed), following procedures stipulated by products manufacturer. To avoid contamination, the non-inoculated seeds were planted first followed with the inoculated seeds. Three seeds were planted and thinned to two plants after full plant establishment. Interplant spacing was maintained at 0.5 m throughout for maize and 0.2 m for legumes. The plant density was kept constant on a total plot area basis set at the optimum for sole crops and kept the same in intercrops. The plant population density of maize and legumes were maintained at 44,000 and 200,000 plants per hectare respectively. Weeding and other agronomic practices were done manually using hand hoe at different growth stages of the crop plant.

Data collection: Plant samples (common bean and lablab) collection involved uprooting of the ten plants which were randomly selected at flowering stage from each plot for the determination of shoots, roots and whole plant nutrient contents namely, N, P, K, Ca and Mg. Before uprooting the plants, the soil was watered and with an aid of a sharpened peg the plants were uprooted and carefully washed by soaking in a half filled bucket. Then the roots and shoots were carefully separated at the ground level. Prior to analysis, the fresh plant samples were washed using distilled water and drip dried. Thereafter, the samples were oven dried at 70 °C to constant weights and ground to a fine powder (0.5 mm sieve) for plant tissue analysis. The concentration of total N was determined by the micro Kjeldahl method while P, K, Ca and Mg was determined using the recommended methods for plant material analysis for various nutrients(Massawe *et al.,* 2016). The dry matter yield determination involved ten whole legumes plant selected randomly at harvesting and sun dried for three days and then oven dried to constant weights at 70ºC. After oven drying, samples were weighed and recorded as dry matter yield in Kg/ ha. The nutrients uptake was calculated following standard method.

Uptake (Kg/ha) = Concentration of nutrient (%) x Dry matter yield (Kg/ha)

Data analysis: A 3-way ANOVA was used to analyze the data collected. The analysis was done using STATISTICA software program 2010. Fisher's least significant difference was used to compare treatment means at 5% level of probability.

RESULTS AND DISCUSSION

Effects of *Rhizobium* inoculation and cropping systems on macronutrients uptake in shoots, roots and whole plant of *P. vulgaris* and *L. purpureus*: The results showed significant differences on the uptake of N, P, K, Ca and Mg in shoots, roots and whole plant of *P. vulgaris* and *L. purpureus* inoculated with *Rhizobium* in two cropping seasons. The macronutrients uptake (N, P, K, Ca and Mg) were higher in whole plant followed by shoots and roots for both cropping seasons (Tables 1, 2 and 3). However, inoculated lablab had more macronutrients uptake

Table 1: Effect of *Rhizobium* inoculation and intercropping systems on shoots macronutrients uptake by two legumes (*P. vulgaris* and L. *purpureus*) in two cropping seasons

Treatments	Season 1 (Kg/ha)					Season 2 (Kg/ha)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Rhizobium										
R-	96.11±2.88b	9.21±0.92b	8.04±0.17b	9.77±0.65b	1.44±0.03a	110.17±3.16b	8.73±0.73b	8.23±0.09b	9.37±0.53b	1.96±0.03b
R+	110.58±2.76a	11.58±0.76a	8.44±0.22a	11.89±0.68a	1.51±0.04a	126.84±3.60a	13.29±0.74a	10.29±0.14a	13.73±0.72a	2.45±0.03a
Legumes										
1	86.86±1.60b	7.16±0.50b	7.28±0.08b	8.64±0.42b	1.31±0.02b	98.61±1.58b	8.91±0.69b	9.10±0.21b	10.45±0.67b	2.15±0.05b
2	119.84±1.44a	13.63±0.85a	9.20±0.16a	13.02±0.71a	1.65±0.03a	138.40±1.91a	13.12±0.80a	9.42±0.19a	12.65±0.73a	2.26±0.04a
Intercropping systems										
1	113.55±4.34a	10.15±1.40a	8.78±0.28a	11.73±1.26a	1.58±0.05a	129.18±5.74a	10.86±1.39a	9.87±0.23a	12.38±1.20a	2.35±0.05a
2	103.15±5.43b	10.28±1.31a	8.31±0.33ab	11.49±1.04ab	1.50±0.06a	118.60±6.14b	10.85±1.19a	9.28±0.37ab	12.12±1.04a	2.21±0.09a
3	101.42±4.54b	10.92±1.49a	8.28±0.31ab	10.73±0.96b	1.48±0.05b	116.13±5.46b	11.48±1.40a	9.26±0.33ab	11.70±1.34a	2.18±0.09b
4	100.57±4.64b	10.86±1.49a	7.76±0.34b	9.48±0.58c	1.39±0.05c	115.53±5.52b	11.55±1.42a	8.84±0.34c	10.39±0.92a	2.15±0.07b
5	98.06±4.56b	9.76±1.27a	8.06±0.28ab	10.72±1.40b	1.44±0.05b	113.09±5.53b	10.33±1.15a	9.05±0.27b	11.15±1.19a	2.14±0.06b
3-Way ANOVA (F-statistic)										
Rhiz	943.9***	5.28*	7.23***	9.25***	7.31***	294.87***	20.81***	299.66***	34.82***	402.79***
Leg	4905.8***	39.1***	170.80***	39.61***	198.69***	1682.02***	17.69***	6.88**	8.83**	21.20***
Cr syst	129.5***	0.18ns	5.21***	1.27*	7.18***	33.51***	0.20ns	8.42***	0.94ns	9.59***
Rhiz*Leg	1.8ns	0.18ns	0.25ns	1.70ns	0.12ns	7.26***	4.07***	8.12***	3.37ns	4.81***
Rhiz*Cr syst	3.9***	3.24ns	2.15ns	2.49ns	1.48ns	1.10ns	0.09ns	4.27***	2.72***	5.64***
Leg* Cr syst	9.0***	0.17ns	1.97ns	2.94**	2.42ns	0.48ns	0.02ns	3.02***	3.45***	5.87***
Rhiz* Leg*Cr Syst	15.5***	0.05ns	2.58**	3.31**	2.47ns	1.90ns	0.16ns	3.53***	3.18***	2.47ns

R-: Without Rhizobium, R+; With Rhizobium, Legume 1: Common bean; Legume 2: Lablab; intercropping System 1, 2, 3, 4 and 5 are sole maize, 0.1m, 0.2m, 0.45m and 0 m of legumes from maize row respectively; Rhiz; *Rhizobium*, Leg; Legume, Cr Syst; Intercropping Systems. Values presented are means ± SE, n=4. *; **; *** = significant at P≤0.05, P≤0.01, P≤0.001 respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter in a column are significantly different from each other at P=0.05 according to Fischer least significance difference (LSD).

Table 2: Effect of *Rhizobium* inoculation and intercropping systems on roots macronutrients uptake by two legumes (*P. vulgaris* and *L. purpureus*) in two cropping seasons

Treatments	Season 1 (Kg/ha)					Season 2 (Kg/ha)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Rhizobium										
R-	3.72±0.09b	2.45±0.08b	1.96±0.09b	1.95±0.07b	0.23±0.01b	4.95±0.18b	2.40±0.06b	1.96±0.06b	1.97±0.08b	0.32±0.01b
R+	6.12±0.19a	2.92±0.10a	2.31±0.12a	2.39±0.07a	0.27±0.01a	6.71±0.29a	3.37±0.07a	2.73±0.09a	2.88±0.11a	0.45±0.01a
Legumes										
1	4.17±0.17b	2.25±0.05b	1.56±0.06b	2.11±0.09a	0.21±0.0b	4.45±0.11b	2.73±0.092b	1.96±0.07b	2.63±0.14a	0.36±0.01b
2	5.66±0.25a	3.12±0.09a	2.71±0.06a	2.24±0.07a	0.29±0.01a	7.21±0.21a	3.05±0.11a	2.73±0.08a	2.22±0.08b	0.41±0.01a
Intercropping systems										
1	5.52±0.39a	2.85±0.12a	2.27±0.19a	2.52±0.19a	0.26±0.01a	6.42±0.48a	3.08±0.09a	2.50±0.15a	2.86±0.27a	0.41±0.02a
2	4.99±0.38ab	2.71±0.17a	2.16±0.18a	2.11±0.10b	0.26±0.01a	5.89±0.41b	2.92±0.20a	2.37±0.17a	2.36±0.17b	0.40±0.02a
3	4.83±0.36ab	2.76±0.18a	2.13±0.18a	2.05±0.11b	0.25±0.02a	5.62±0.44b	3.01±0.16a	2.38±0.15a	2.35±0.17b	0.38±0.02b
4	4.81±0.37ab	2.49±0.14b	2.08±0.15a	2.21±0.06ab	0.23±0.01a	5.77±0.41b	2.69±0.16b	2.31±0.15a	2.42±0.09b	0.37±0.02b
5	4.43±0.38b	2.62±0.17ab	2.04±0.17a	1.96±0.11b	0.24±0.01a	5.45±0.46c	2.73±0.17b	2.17±0.16a	2.13±0.17c	0.36±0.02b
3-Way ANOVA (F-statistic)										
Rhiz	4764.97***	42.43***	25.69***	22.7***	55.32***	489.99***	188.54***	120.04***	68.1***	387.41***
Leg	1823.89***	147.84***	272.26***	1.95ns	246.19***	1210.89***	19.98***	118.07***	14.12***	73.20***
Cr syst	102.61***	2.92**	1.23ns	4.26**	8.38***	17.13***	4.48**	2.38ns	4.82***	9.11***
Rhiz*Leg	302.74**	3.12ns	6.08**	0.06ns	19.72**	81.66***	1.49ns	8.26ns	1.46ns	18.30***
Rhiz*Cr syst	14.38***	2.39ns	0.14ns	2.47ns	1.04ns	0.49ns	4.67***	0.26ns	3.18***	1.14ns
Leg* Cr syst	8.70***	7.45***	1.22ns	0.91ns	10.97**	1.89ns	4.22***	0.17ns	1.15ns	1.05ns
Rhiz* Leg*Cr Syst	17.98***	0.52ns	0.15ns	0.54ns	2.26ns	0.12ns	0.69ns	0.68ns	1.07ns	4.27***

R-: Without *Rhizobium*, R+: With *Rhizobium*, Legume 1: Common bean; Legume 2: Lablab; intercropping System 1, 2, 3, 4 and 5 are sole maize, 0.1m, 0.2m, 0.45m and 0m of legumes from maize row respectively; Rhiz: *Rhizobium*, Leg: Legume, Cr Syst: Intercropping Systems. Values presented are means ± SE, n=4. *: *; **: ***; *** = significant at P≤0.01, P≤0.001 respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter in a column are significantly different from each other at P=0.05 according to Fischer least significance difference (LSD).

Table 3: Effect of *Rhizobium* inoculation and intercropping systems on whole plant macronutrients uptake by two legumes (*P. vulgaris* and *L. purpureus*) in two cropping seasons

Treatments	Season 1 (Kg/ha)					Season 2 (Kg/ha)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Rhizobium										
R-	99.83±2.96b	11.66±0.97b	9.99±0.26b	11.73±0.66b	1.67±0.04a	115.12±3.32b	11.13±0.75b	10.19±0.14b	11.33±0.53b	2.28±0.03b
R+	116.69±2.94a	14.50±0.83a	10.75±0.31a	14.28±0.69a	1.78±0.04a	133.55±3.88a	16.67±0.76a	13.02±0.18a	16.61±0.71a	2.90±0.03a
Legumes										
1	91.04±1.75b	9.41±0.51b	8.84±0.11b	10.74±0.44b	1.51±0.02b	103.05±1.67b	11.64±0.74b	11.07±0.26b	13.08±0.72b	2.51±0.06b
2	125.49±1.66a	16.75±0.88a	11.91±0.19a	15.25±0.73a	1.93±0.03a	145.62±2.11a	16.17±0.86a	12.14±0.26a	14.86±0.76a	2.68±0.05a
Intercropping systems										
1	119.06±4.67a	13.00±1.49a	11.05±0.45a	14.25±1.33a	1.85±0.06a	135.60±6.21a	13.94±1.46a	12.37±0.37a	15.25±1.28a	2.76±0.07a
2	108.15±5.71b	12.99±1.42a	10.46±0.49b	13.60±1.07a	1.76±0.07a	124.48±6.53b	13.77±1.29b	11.65±0.52b	14.48±1.11b	2.61±0.11b
3	106.25±4.81b	13.68±1.59a	10.41±0.48b	12.78±0.97b	1.72±0.07a	121.75±5.88b	14.49±1.48a	11.65±0.45b	14.04±1.39b	2.57±0.10b
4	105.38±4.95b	13.36±1.57a	9.84±0.39b	11.69±0.58c	1.61±0.05b	121.29±5.90b	14.25±1.51a	11.15±0.39b	12.81±0.93d	2.52±0.08c
5	102.49±4.89c	12.38±1.40b	10.10±0.44b	12.68±1.43b	1.68±0.06b	118.55±5.98b	13.07±1.29b	11.22±0.42b	13.28±1.22c	2.50±0.08c
3-Way ANOVA (F-statistic)										
Rhiz	1258.7***	7.13***	19.81***	13.67***	17.20ns	336.65***	28.95***	369.99***	52.25***	524.49***
Leg	5254.3***	47.48***	332.77***	42.49***	285.52***	1797.14***	19.34***	53.36***	5.97**	38.40***
Cr syst	143.7***	0.17*	5.80***	1.58**	9.88**	34.99***	0.22*	8.83***	1.40**	11.83***
Rhiz*Leg	0.0ns	2.7ns	0.4ns	1.8ns	0.3ns	11.0***	3.5ns	0.9ns	4.2**	1.0ns
Rhiz*Cr syst	4.3**	0.1ns	1.3ns	2.7**	1.0ns	1.1ns	0.0ns	3.4**	2.9**	4.9***
Leg* Cr syst	8.3***	0.1ns	2.7**	3.1**	4.5**	0.4ns	0.1ns	2.4ns	3.4**	5.5***
Rhiz* Leg*Cr Syst	16.7***	0.2ns	2.1ns	3.6**	1.9ns	1.8ns	0.1ns	1.9ns	3.3**	1.2ns

R-: Without *Rhizobium*, R+: With *Rhizobium*, Legume 1: Common bean; Legume 2: Lablab; intercropping System 1, 2, 3, 4 and 5 are sole maize, 0.1m, 0.2m, 0.45m and 0m of legumes from maize row respectively; Rhiz; *Rhizobium*, Leg; Legume, Cr Syst; Intercropping Systems. Values presented are means ± SE, n=4. *; **; *** = significant at P≤0.05, P≤0.01, P≤0.001 respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter in a column are significantly different from each other at P=0.05 according to Fischer least significance difference (LSD).

compared with inoculated common bean (Tables 1, 2 and 3) in the whole plant, shoots and roots. The macronutrients uptake observed in cropping season 2 was greater than in cropping season 1 probably due to incorporation of plant residues from the first cropping season harvest that increased more soil nutrients to plant. The addition of crop residues increase the exchange power of some polyvalent cations such as Ca^{2+} and Mg^{2+} and making them available for plant uptake (Marschner, 1989). Studies by Makoi *et al.* (2013) and Ahmad *et al.* (2005) indicated the greater uptake of these macronutrients could be ascribed to the synthesis of phytohormones, siderophores, indole 3-acetic acid (IAA) and cytokinins by the rhizobia which directly stimulated the plant growth, thus, increasing macronutrients for uptake by plant. Greater uptake of these macronutrients could also result from the improved rhizosphere pH as reported by Bambara and Ndakidemi (2010). *Rhizobium* inoculation has also been reported to modify the rhizoplane by releasing dead cells which may contain macronutrients or biomolecules that can solubilise unavailable to available nutrients as previously observed by Makoi *et al.* (2013). Greater plant nutrient requirement during the N_2 fixation by legumes such as *P. vulgaris* and *L. purpureus* has similarly necessitated greater

uptake of such macronutrients from the rhizosphere to the plant. The presence of small amount of macronutrients uptake in plots with no *Rhizobium* inoculation in this study indicated the existence of native *Rhizobium* strains in the soil that were effective in fixing N as also reported by (Maingi *et al.*, 2001).

Legumes intercrop had decreased roots uptake in the order of N>P> K>Ca> Mg in both cropping seasons but increased shoots and whole plant uptake in the same order (Tables 1, 2 and 3). This was due to the fact that most macronutrients are motile that move from the roots to the young growing part of the plant hence more concentration in the above ground part compared with the roots. Improved availability of P, K, Ca and Mg in the study area is advantageous to cropping systems involving *P. vulgaris* and *L. purpureus* which require greater amount of these nutrients for normal growth and N_2 fixation. The remarkable differences were observed between shoots, roots and whole plant on the uptake of macronutrients in plant with different cropping systems which could be attributed to physiological process which takes place in above ground plant part compared with below ground plant part.

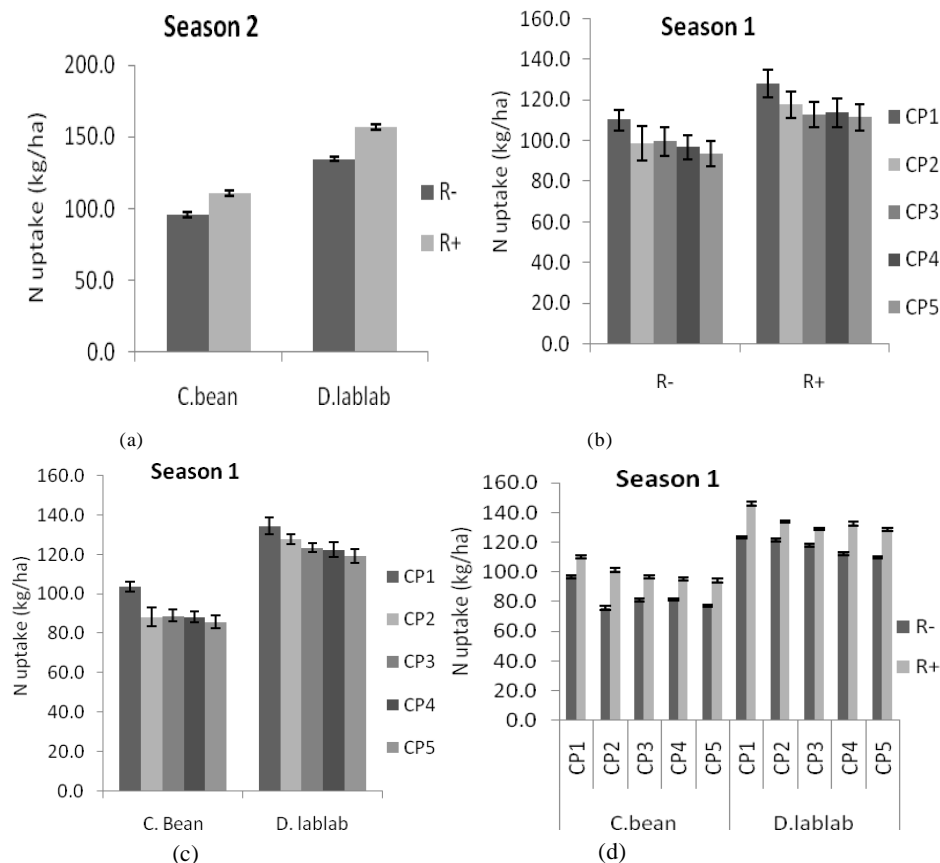Cropping systems significantly affected shoot and whole plant uptake of N, K, and Mg except P and Ca in

Figure 1: Interactive effects of **(a)** *Rhizobium* and legumes; **(b)** *Rhizobium* and cropping systems; **(c)** legumes and cropping systems; **(d)** *Rhizobium*, legumes and cropping systems on whole plant N uptake in cropping season 2 and 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C.bean: *Phaseolus vulgaris*, D. lablab: *Lablab purpureus,* CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

two cropping seasons (Tables 1 and 3). Sole legumes had the highest macronutrients (N, K, Ca and Mg) uptake than other intercropping systems except for the P uptake. With roots, the cropping systems also significantly increased roots uptake of all macronutrients listed above except K during both the cropping seasons (Table 2). The sole legumes were superior in roots macronutrients but relatively close to other intercropping systems. A study by Thobatsi (2009) reported the possible advantage of intercropping legumes with non-legumes may be more efficient use of soil nutrients. This has been supported by the current study through increments of more macronutrient uptake in maize intercrops compared with the sole maize.

Interactive effect of *Rhizobium* inoculation and cropping systems on macronutrients uptake in whole plant of *P. vulgaris* and *L. purpureus*: The study showed significant (P≤0.001) interactive effect between *Rhizobium* and legumes on whole plant N uptake in cropping season 2 (Fig. 1a); *Rhizobium* and cropping systems; legumes and cropping systems and *Rhizobium*, legumes and cropping systems on whole plant N uptake in cropping season 1 (Fig. 1b, 1c, 1d). A work by Makoi *et al.* (2013) reported that N_2 fixation is a very expensive process and requires greater amounts of nutrients including P and K uptake by legumes. This argument could probably explain why the uptake of these macronutrients was as distinct with *Rhizobium* inoculated treatments compared with no *Rhizobium* inoculation, suggesting that greater amounts of P, K and Mg may have been utilized during N_2 fixation process and nodulation compared with no *Rhizobium* inoculation. Regardless of the cropping systems, the amount of macronutrients uptake was significantly higher with *Rhizobium* inoculation, *L. purpureus* in sole cropping system and therefore the N uptake in whole plant change with *Rhizobium* inoculation and cropping systems in both cropping seasons.

CONCLUSIONS

According to our results, the highest macronutrients uptake were observed in shoots and whole plant of inoculated legumes in sole cropping system, this implies that the use of *Rhizobium* in sole cropping system affected nutrients use efficiency by the crops. On other side this leads to deplete the macronutrients in the soil. Where legumes were intercropped with maize, macronutrients uptake were low in legumes due to competition of the maize component. Therefore, increasing macronutrients uptake through *Rhizobium* inoculation and cropping systems have to be in line with organic soil nutrients replenishments. The higher macronutrients uptake in the shoots and whole plant are associated with higher yields of the component crops in the intercrops which could contribute to the improvement of macronutrient status of the crops, leading to improved health of people that depend on these crops.

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