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Effects of *Rhizobium* inoculation and cropping systems involving common bean and lablab on water use efficiency, weeds and insects pests' infestation

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Abstract

Field experiments were conducted during two cropping seasons (2015-2016) at Selian Agricultural Research Institute (SARI) farm to determine the effect of *Rhizobium* inoculation and intercropping systems of maize and legumes (common bean and lablab) on soil moisture content, weeds and insect pests' infestation. 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 rhizobia), 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 results showed that the population of the insect pests had no significant effect between the sole crop and intercrops in both seasons while from field observation, the weeds population decreased for intercrop systems compared with sole crop system. On the other hand, soil moisture content had significant effect (P≤0.001) due to *Rhizobium* inoculation, legumes and cropping systems in both seasons. The result showed significant (P≤0.01) interactive effect between *Rhizobium* and cropping systems on insect pests' infestation in season 1. The interaction between *Rhizobium*, legumes and cropping systems had significant effect (P≤0.01) on soil moisture content in both seasons. These suggest further research to identify cropping systems that will decrease insect pests' infestation, weeds and increases soil moisture content.

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Introduction

Intercropping is the practice of growing different crops in the same field (Mampana, 2014). There are many spatial combinations possible for intercropping, including mixed intercropping, in which different crops are planted in the same row or without proper rows arrangement, and row intercropping, which involves planting different crops in alternating rows (Lithourgidis *et al.,* 2011). The component crops of an intercropping system do not necessarily have to be sown at the same time nor they have to be harvested at the same time, but they should be grown simultaneously for a great part of their growth periods (Ashish *et al.,* 2015). Studies by Mampana (2014) and Najafi and Abbas (2014) reported the benefits of intercropping to be increasing soil water content, weed suppression, reducing insect pest populations and diseases. Intercropping can improve soil water content through shading effect of canopy cover and protection of the soil surface from raindrop impact, thereby increasing water infiltration into the soil (Ghanbari *et al.,* 2010; Mampana, 2014; Walker and Ogindo, 2003). In sole cropping, water losses from bare inter-rows of crops planted may lead to lower water content (Passioura and Angus, 2010). However, crops grown in intercrops may compete for water sources if water supply is less than the potential water losses from the surface and plants (Lithourgidis *et al.,* 2011). A study by Miriti *et al.* (2012) indicated the similar results of more water content under maize/cowpea intercrop compared with a sole maize crop because the intercrop develop canopy cover which increases more water to transpire leading to decreased water content in the soil.

Annually, 10% of the world's agricultural production is lost due to weed competition despite their tight control (Parviz, 2014). Intercropping has been reported to reduce weeds population than monocropping because the systems use resources more effectively than a monocropping and therefore the amount that could be available for use by weed decreases (Javanshir *et al.,* 2000; Ngome *et al.,* 2012,). For example, a study by Ashish and Yadav (2013) on sole pearl millet recorded the maximum mean removal of nutrients by different weeds to an extant 16.29 kg N ha^{-1} and 2.38 kg P ha^{-1}, respectively than pearl millet intercropped with cluster bean/moth bean. Lower uptake of nutrients by different weeds under intercropping systems may be attributed to hang up of weed growth and reduced crop weed competition due to smothering effect of intercrops on weeds which led to lower dry matter production, consequently resulting in lower uptake of nutrient by weeds.

Intercropping discourages the multiplication and spread of insects' pest and diseases as they would be on the uniform crop. A study by Dimitrije (2013) reported the impact of plant diversification on pests and beneficial arthropods population dynamics in agricultural ecosystems and provided some evidence that habitat manipulation techniques like intercropping can significantly influence insect pest and diseases control. Root exudates from neighbouring plants can produce defensive compounds that could repel or could be effective against soil born insects and diseases (Ndakidemi and Dakora, 2003). Other studies by Sarker *et al.* (2007) and Demitrije (2013) indicated that components of intercropping system suffer significantly less damage from insects compared with their cultivation as sole crops which has positive impact on yield. It is important to understand the mechanisms by which diversification of habitat may favour pest and disease management (Gurr *et al.,* 2003). The efficiency and sustainability of intercropping pattern as non-chemical method of insect pests and weeds management especially at the small farm level depend on the choice of compatible crops and the optimum population to minimize interference and form a good component of integrated weed management at the low input farm level. The use of intercropping systems provides an option for improving water use efficiency, control weeds, insects and diseases for farmers that are limited in their chemical use. However, there are limited studies involving *Rhizobium* inoculated legumes - maize intercrops pattern to assess the efficacy of intercropping pattern in controlling and balancing the above constrains in cereal-legumes production in Tanzania.

Therefore, this study aimed at assessing the effects of *Rhizobium* inoculated legumes and maize intercropping systems on soil moisture conservation, weeds and insect pests control in smallholder farmers of northern Tanzania.

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 (from April 2015 to September 2015 and from October 2015 to February 2016). 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 temperature ranges from 22°C to 28°C whiles the mean minimum temperature ranges from 12°C to 15°C respectively.

Experimental design and treatments application

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 rhizobia), 2 legumes (*P. Vulgaris* and *L. purpureus)* and 5 cropping systems (sole maize, sole legumes, 1 row maize to 1 row legumes (1:1) i.e. 0m or 0.45m of legume from maize row, 1 row maize to 2 rows of legumes (1:2) i.e. 0.1m or 0.2m of legumes from maize rows). The plots measured 4m × 4m with 5 rows of maize spaced at (0.9 m x 0.5m) apart and 8 rows of legumes spaced at (0.5m × 0.2m).

The plots were interspaced by 1m to allow management of crops. The crops were planted at the onset of rainfall. Prior to planting, phosphate fertilizer as triple superphosphate was applied to all treatment plots at the rate of 20kg P/ha to supplement the low P reported from the study site by Massawe *et al.* (2016). The fertilizer was uniformly applied in to the holes and covered with little soil before planting maize or legume seeds to avoid seeds burning. 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 Dolichos lablab variety (Rongai) were obtained from Selian Agricultural Research Institute-Arusha-Tanzania. Before sowing, the specific legume seeds were thoroughly mixed with specific *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 was done at 4 weeks after planting (WAP) for all cropping patterns.

Plate 1. Weeding done at 4 weeks after planting.

Data collection

The soil moisture determination involved sampling the soil from the research plots of which 10g of the soil sample was weighed and recorded as weight of wet soil. The weighed sample was placed in the oven at 105°C, and dry for 24 hours or overnight. Then the oven dried sample was weighed and recorded as weight of dry soil. The sample was returned to the oven and dry for several hours until there is no difference between any two consecutive measurements of the weight of dry soil. Soil moisture content (% volume) was determined by using gravimetric method (Janeth *et al.,* 2014). MC= $\frac{(Ww\text{-}Wd)^*}{Wd}100$

Where; MC = Moisture content (%), Ww = Weight of wet soil (g), Wd = Weight of dry soil (g)

Assessment of insect's population

Insects' population were investigated in all the plots during the two cropping seasons. The number of insects from 10 randomly selected plants of each plot was counted and recorded twice for every month until harvest.

Plate 2. Insect pests identified in sole common bean (White aphids, black aphids, parasaitoids and leaf eating caterpillars).

Plate 3. Insect pests identified in sole lablab (Leaf bettle and pod borer).

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

Effects of Rhizobium inoculation and cropping systems on insect pests' infestation and soil moisture conservation

The results from the current study had no significant differences on the insect pests' occurrences on the sole crop and intercrops in both cropping seasons (Table 1). However, the soil moisture content was significantly ($P \leq 0.001$) influenced by *Rhizobium* inoculation with an increase of 18.04% and 18.81% for season 1 and 2, respectively when compared with the unionculated controls (Table 1).

The results showed that maize intercropping with inoculated legumes significantly increased the soil moisture content. The intercropping systems in this study had effects on weeds population infestation regardless of the legumes types used as compared with sole cropping (data not shown).

Legumes also had significant effect ($P \leq 0.001$) on the soil moisture content where lablab was superior to common bean by an increase of 60.02% and 60.65% for season 1 and 2, respectively (Table 1). Cropping systems had significant effects ($P \leq 0.001$) on soil moisture content by an increase of 10.81% and 11.07% for season 1 and 2, respectively.

Interactive effect of Rhizobium inoculation, legumes and cropping systems on insect pests' infestation and soil moisture conservation

The study showed significant ($P \leq 0.01$) interactive effect between *Rhizobium* and cropping systems on insect pests infestation in cropping season 1 (fig. 1). Similarly, the study indicated interactive effect between *Rhizobium* and legumes (fig. 2); *Rhizobium* and cropping systems (fig. 3); *Rhizobium*, legumes and cropping systems on soil moisture conservation in cropping season 1 and 2, respectively (Fig. 4).

Table 1. Effect of *Rhizobium* inoculation and intercropping systems on insect pests' infestation and soil moisture content in two cropping seasons.

Treatments	Season 1		Season 2	
	Number of Insect/ pests	Soil moisture content (%)	Number of Insect/ pests	Soil moisture content (%)
Rhizobium				
R-	0.80±0.10a	19.16±1.35b	1.03±0.11a	18.64±1.33b
R+	0.90±0.12a	23.38±1.60a	1.05±0.14a	22.96±1.59a
Legumes				
1	0.78±0.10a	12.15±0.25b	1.10±0.13a	11.75±0.25b
2	0.93±0.13a	30.39±0.51a	0.98±0.13a	29.86±0.52a
Intercropping systems				
1	1.06±0.25a	19.55±2.37b	0.81±0.16a	19.11±2.39c
2	1.06±0.19a	21.57±2.43a	1.13±0.18a	20.97±2.39b
3	0.75±0.14a	21.53±2.46a	0.81±0.16a	21.09±2.43ab
4	0.69±0.15a	21.79±2.48a	1.44±0.27a	21.37±2.46ab
5	0.68±0.15a	21.92±2.43a	1.00±0.18a	21.49±2.42a
3-Way ANOVA (F-statistic)				
Rhiz	0.43ns	1051.2***	0.02ns	854.93***
Leg	0.96ns	19632.3***	0.47ns	15032.79***
Cr syst	1.31ns	44.9***	1.63ns	34.61***
Rhiz*Leg	0.96ns	144.9***	0.02ns	127.00***
Rhiz*Cr syst	3.51**	3.5**	1.10ns	3.10**
Leg* Cr syst	1.23ns	1.3ns	1.27ns	0.76ns
Rhiz* Leg*Cr Syst	0.96ns	6.1***	0.07ns	3.33**

R-: Without *Rhizobium*, R+; With *Rhizobium*, Legume 1: Common bean; Legume 2: Lablab; intercropping System 1, 2, 3, 4 and 5 are sole maize, 10cm, 20cm, 45cm and 0cm of legumes from maize row respectively; Rhiz; *Rhizobium*, Leg; Legume, Cr Syst; Intercropping Systems. Values presented are means ± SE, n=4. **; *** = significant at $P \leq 0.01$, $P \leq 0.001$ respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at P=0.05 according to Fischer least significance difference (LSD).

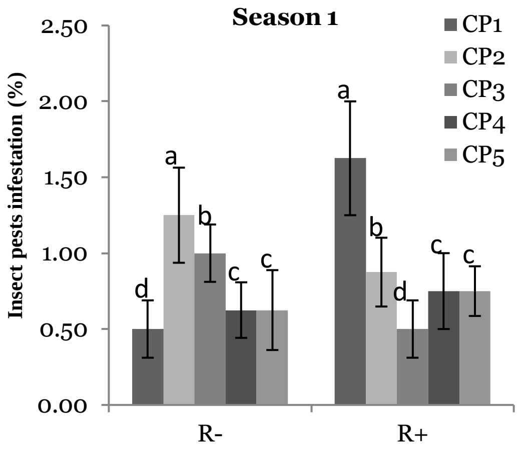


Fig. 1, Interactive effects between *Rhizobium* and cropping systems on insect pests infestation for cropping season 1 (R-: Without *Rhizobium*, R+: With *Rhizobium*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

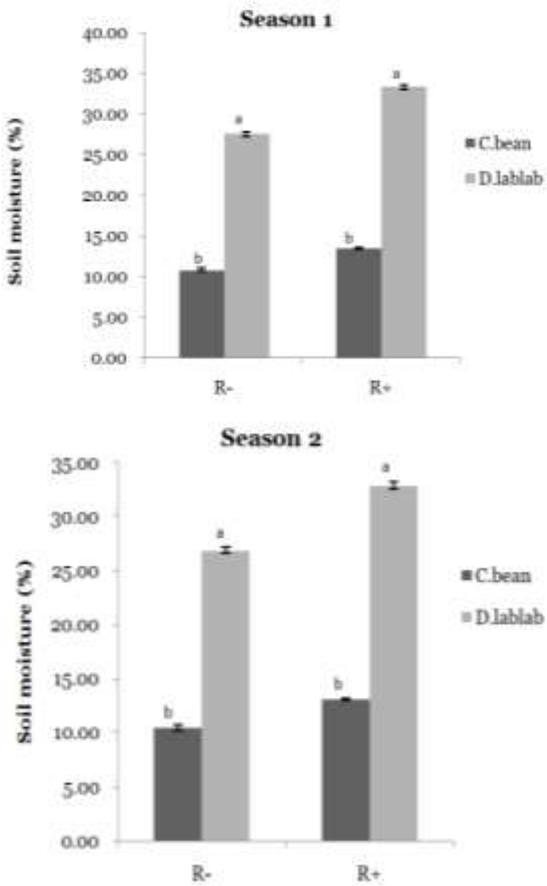


Fig. 2. Interactive effects between *Rhizobium* and legumes on soil moisture content for season 1 and 2 (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. Bean: Common bean, D. lablab: Dolichos lablab)

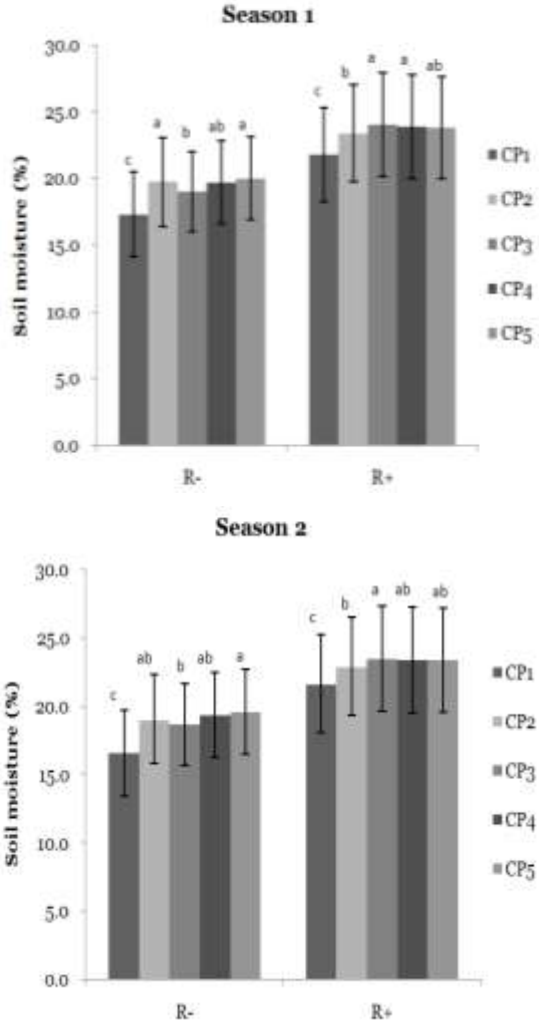
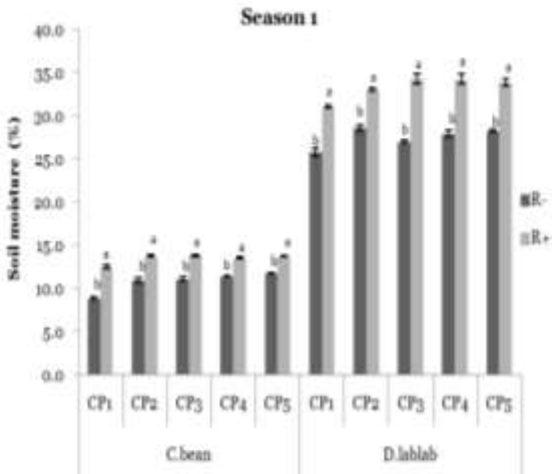


Fig. 3. Interactive effects between *Rhizobium* and cropping systems on soil moisture content for season 1 and 2 (R-: Without *Rhizobium*, R+: With *Rhizobium*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5).



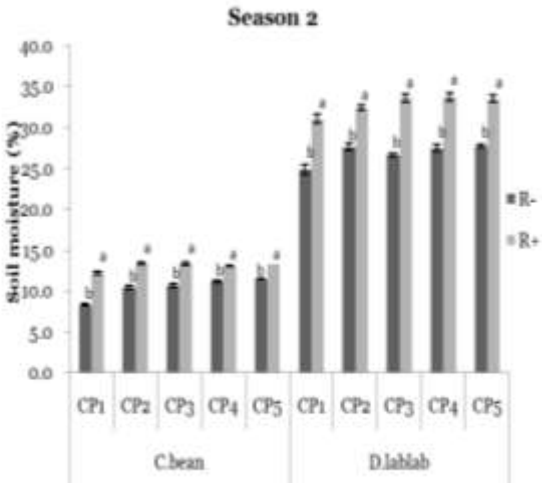


Fig. 4. Interactive effects between *Rhizobium*, legumes and cropping systems on soil moisture content for season 1 and 2 (R-: Without *Rhizobium*, R+: With *Rhizobium*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5, C. Bean: Common bean, D. lablab: Dolichos lablab)

Discussion

The highest soil moisture was recorded in cropping systems 4 and 5 (1 row maize to 1 row legumes (1:1) i.e. 0m or 0.45m of legume from maize row) and the lowest values of soil moisture were recorded at cropping system 1 (sole legumes). This indicates that the maize intercropped with legumes (lablab and common bean) led to increased soil water content. Soil moisture content was reduced significantly in the sole crop of legumes due to high evaporation. Contrarily, soil moisture content increased significantly in the intercrop of legumes and maize due to low evaporation from the intercrop which provided better soil cover compared with sole legumes. Similar to our study, Passioura and Angus, (2010) reported that evaporative losses from the bare inter-rows of crops planted in monoculture may lead to lower water content. The plant root systems among species and cropping systems may also have influenced the water content in the soil. The average soil water content in the lablab -maize intercropping plots was higher than the average soil water content of the component crops. Ghanbari-Bonjar (2010) reported the main reason for high moisture content in the intercrops as mainly due to the adequate ground cover provided by legumes hence prolonged water infiltration and retention, thus raising the overall soil moisture retention and soil water holding capacity. The high soil moisture content recorded in the intercropping systems in the current study conforms to the findings of Dahmardeh and Rigi (2013) who reported that there is a positive effect of the intercropping in conservation of soil moisture.

The low incidence of weeds in the intercrop plot (field observation) irrespective of planting patterns in this study was attributed to more photosynthetic active radiation (PAR) interception and possible interference from the component crops, in addition to ground cover effect. A study by Orluchukwu1 and Udensi, (2013) reported that in mixed intercropping pattern, the advantages of dense canopy and close covering of soil surface by crops of different leaf shapes and heights affects the weeds population.

Intercropping systems reduced the incidence of pests due to increased botanical diversity. The increases in number of insect pests counted per plant in this study were very minimal in intercrops but the occurrence was closely similar to those of sole crops. Dimitrije, (2013) reported that adding more plant species to a cropping system can affect insect pests in two ways; Firstly, neighbouring plants and microclimatic conditions is altered and secondly the host plant quality e.g. morphology and chemical content is also altered. Components of intercrops are often less damaged by pest and disease organisms than when grown as sole crops, but the effectiveness of this escape from attack often varies unpredictably. The study showed the significant interactive effects between *rhizobium* inoculation, legumes and cropping system on soil moisture content. This was attributed by the changes in leaf structure of legumes species and minimization of evaporative space directly from the soil and hence increasing soil water content. The complex interaction among the intercropped crops, inoculation with rhizobia and legumes implies that the increase of soil moisture content in intercropping might be related to the modification of rhizosphere of component crops and microbial community.

Conclusion

Intercropping maize and *Rhizobium* inoculated legumes (*P. vulgaris* and *L. purpureus*) increased the soil moisture content, weed suppression at the acceptable level and reduced insect pests' infestation than the sole cropping pattern. On other hand, crop monocultures (sole cropping pattern) encourage the multiplication and spread of pest insects because of the uniform crop while the intercropping practices help to mask plants from pests and can provide food for beneficial organisms. Intercropping can therefore be a sustainable option for smallholders' farmers under dry land cropping conditions and provides an option for insect control for organic farmers that are limited in their chemical use.

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