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RESEARCH ARTICLE

Comparative Effects of Soil Nutrient Status and Texture on Mycorrhiza – Legume Base Cropping System in Two Soil Types of Nigeria

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ABSTRACT

Soil nutrients and texture determine the rate of response of crops to mycorrhizal colonization. A two-year field experiment was conducted to compare the effects of mycorrhiza – legume base cropping systems at Ekpoma and Uzeba, both in Edo State, Nigeria. The experiment was a factorial, fitted into a RCBD with three replicates. The treatments consist of two levels of mycorrhiza and three planting systems. The descriptive statistics were used to analyse the data, and the Duncan Multiple Range Test was used to separate means ($p \leq 0.05$). Ekpoma soil is moderately suitable while Uzeba soils are low in nutrient with loamy sand and sand texture respectively. The interaction of the mycorrhiza with pigeon pea significantly ($p \leq 0.05$) increased the soil nutrient and nitrogen fixation in Ekpoma compared to the Uzeba location. The growth and yield of maize in Ekpoma were significantly ($p \leq 0.05$) higher compared to that of Uzeba with or without mycorrhiza inoculation, with an average yield of 2.24 t ha^{-1} in Ekpoma and 1.51 t ha^{-1} in Uzeba. The inoculation of *Glomus clarum* increased the grain yield of pigeon pea by 48 % and 37 % compared to non-mycorrhizal pigeon pea for both sole and intercrop in both locations. The residual effect of *Glomus clarum* and pigeon pea on maize yield was 53% higher in Ekpoma than found in Uzeba. The loamy sand texture of Ekpoma soil enhanced the efficiency of mycorrhiza utilisation compared to the sandy texture of Uzeba.

Keywords: *Glomus clarum*, maize, pigeon pea, soil nutrient, nitrogen fixation, yield

INTRODUCTION

The degradation of soil chemical and physical qualities necessitates improvement of soil fertility for sustainable crop production. Soil structure and texture influence water and nutrient retention, ion adsorption, and mycorrhizal colonisation. These qualities affect the soil's nutritional content. Fertilizers have been shown to improve soil fertility and crop yield, but their high cost, lack of availability, and environmental effect are key obstacles. Organic or biofertilizers are used to achieve a balance between yield and environmental aims. The rhizosphere is a plant–microbe interaction zone where microorganisms colonise developing roots. So, using biofertilizers to boost soil fertility is recommended. Mycorrhizal fungal inocula as a biofertilizer has been shown to promote nutrient uptake by plants, especially phosphorus, boosting growth and production of crops like pigeon pea (Chikowo et al., 2004).

Effective nodulation and N_2 fixation depend on arbuscular mycorrhizal fungi supplying phosphorus to legume root nodules (Requena et al. 2001). Leguminous plant used to build soil, agroforestry systems, and cover crops (Valenzuela and Smith, 2002). Pigeon pea may fix nitrogen and supply organic matter from its litter fall, improving soil quality and structure (Odeny, 2007). Pigeon peas are thought to fix more nitrogen than other leguminous crops, between 40-250 kg/ha (Chikowo et al. 2004). The amount of nitrogen and phosphorus released by root decomposition was over 40 kg/ha, providing a potentially useful pool of nutrients for the following crops in the rotation (Barber and Navarro, 1994). Pigeon peas can also sequester carbon, which helps mitigate the consequences of climate change (Waddington et al., 2007).

Furthermore, inoculation of mycorrhiza to pigeon pea base cropping system will enhance the growth and yield of the companion crop (maize) and soil quality. The increase in yield of crops in a legume – mycorrhizal base cropping system depends on the native nutrient available at the planting. The practice of mycorrhizal fungi base intercropping system is very rear among farmers. It is therefore the objectives of this research to investigate: i) effects of soil texture and nutrient on mycorrhizal use efficiency, ii) the effect of mycorrhizal fungi on the growth and yield of maize - pigeon pea intercrop and iii) the synergetic effects of mycorrhiza – pigeon pea base cropping system on nutrient uptake at Ekpoma and Uzeba.

MATERIALS AND METHODS

Experimental site

A two-year study was carried out in 2008 and 2009 at Ekpoma and Uzeba, Edo State, Nigeria. Ekpoma lies between Latitude North 6° 45' 34" and longitude East 6° 8' 27", average annual rainfall of about 1500mm. While Uzeba lies between latitude 6° 58' 56.98" North and longitude East 5° 54' 30.75" East, with average rainfall of 1300mm annually.

Soil Analysis

Top soil (0-15 cm) was collected before to each planting season, dried, sieved, and tested for chemical and physical qualities. The hydrometer was used to measure particle size (Bouyoucous, 1962). The pH was tested in water (1:1, soil:water), (IITA, 1979). The available phosphorous was measured by the Bray extraction method (Anderson and Ingram, 1993). Kjeldahl technique determined total nitrogen (Bremner and Mulvaney 1982). Calcium and magnesium were evaluated by atomic absorption spectrophotometer while potassium was extracted with ammonium acetate (IITA, 1979). It was a factorial experiment with three replications in a Randomized Complete Block Design (RCBD). There were two degrees of mycorrhiza (*Glomus clarum*) and three planting systems (sole maize, sole pigeon pea, maize-pigeon pea hedgerow). The inoculants employed were *Glomus clarum* and Suwan-1-SR for maize and IAR&T50 for pigeon pea (long duration). Planting rates for maize and pigeon pea were 1,200 kg/ha and 300 kg ha^{-1}, respectively. Plant height, stem girth, number of leaves, dry matter shoot and grain yield were all assessed, as was nutrient uptake by multiplying nutrient concentration in plant tissue by dry matter weight.

Nutrient uptake = concentration x dry matter yield.

The residual experiment was carried out in 2009 and the above parameters were also measured. Nitrogen fixation was evaluated by xylem sap technique (People et al. 1989).

Statistical Analysis: ANOVA was used to examine data from laboratory and field experiments (SAS, 1995). DMRT was used to separate the means.

RESULTS

Soil Analysis

The initial soil pH at Ekpoma and Uzeba were 5.93 and 5.91, the inoculation of mycorrhiza and the impact of pigeon pea raised the pH level to 6.2 and 6.1 respectively. The values of organic carbon were increased by 86.6 % and 40 % in mycorrhizal pigeon pea and sole pigeon pea plots in Ekpoma compared to Uzeba location (Table 1). The inoculation of mycorrhiza to pigeon pea results to increase of nitrogen, phosphorus, potassium, magnesium and calcium in the soil (Table 1). This nutrient and ECEC were higher in treatments at Ekpoma than that of Uzeba. The textural class of Ekpoma and Uzeba soil was loamy sand and sand respectively (Table 1).

Growth parameters

The inoculation of mycorrhiza significantly ($p \leq 0.05$) increased the height and stem girth of both sole and intercrop maize and pigeon pea compared to non-mycorrhizal maize and pigeon pea in 2008 and 2009 cropping season at Ekpoma. There was no significant difference in stem girth of maize and pigeon pea at Uzeba in both cropping season (Table 2). The stem girth of pigeon pea was 49.5% higher in Ekpoma compared to that Uzeba. It was also observed that the growth of maize and pigeon in Ekpoma were significantly ($p \leq 0.05$) increased with inoculation of mycorrhiza compared to that of Uzeba in both cropping seasons.

Grain yield

In 2008, the grain yield of sole and intercrop maize inoculated with Glomus clarum was 2.24 t ha^{-1} and 1.87 t ha^{-1}, respectively, in Ekpoma. Compared to non-mycorrhizal pigeon pea, mycorrhizal pigeon pea had better grain yield and above-ground biomass (Table 3). In Ekpoma, residual mycorrhizal inoculation boosted average yields to 2.65 t ha^{-1} and 2.58 t ha^{-1}, while in Uzeba, average yields were 1.51 t ha^{-1} and 1.73 t ha^{-1}, respectively. The maize dry matter yield at Uzeba was considerably ($p \leq 0.05$) lower than at Ekpoma. The pigeon pea and mycorrhizal interaction increased maize grain and dry matter production ($p \leq 0.05$), (Table 3).

Nitrogen fixation

Interaction of mycorrhiza and pigeon pea nodules results in significant ($p \leq 0.05$) increased of nitrogen fixation per hectare. Mycorrhizal pigeon pea were74.4% and 43.0 % higher than non-mycorrhizal sole and intercrop pigeon pea (Table 3 & 4).

Nutrient uptake

The nitrogen uptake in maize was significantly ($p \leq 0.05$) higher in mycorrhizal maize - pigeon pea intercrop (AM+MP) with the value of 301 kg ha^{-1} compared to other treatments; non mycorrhizal intercrop (AM-MP) value was 241.2 kg ha^{-1}, mycorrhizal sole maize (AM+Sole maize) value was 261.9 kg ha^{-1}, non-mycorrhizal sole maize (AM-Sole maize) value was 208.7 kg ha^{-1}. Phosphorus and potassium uptake were significantly ($p \leq 0.05$) higher in mycorrhizal maize and pigeon pea compared to other treatments. The result shows that mycorrhizal inoculation positively influenced the nutrients uptake by plants. The interaction of pigeon pea and mycorrhiza increased uptake of nitrogen and other nutrients in maize and pigeon pea in the second season experiment (Table 5). At Uzeba site in 2008, inoculation of mycorrhiza on maize and pigeon pea increased significantly the uptake of nitrogen, phosphorus and potassium compared to other treatments where mycorrhiza was not applied (Table 5). Nitrogen, phosphorus and potassium uptake were significantly ($p \leq 0.05$) higher in maize and pigeon pea inoculated with mycorrhiza due the interaction between mycorrhiza and pigeon pea. Comparing the nutrient uptake from both locations; Ekpoma had significantly ($p \leq 0.05$) higher nutrient uptake in both maize and pigeon with or without mycorrhizal inoculation compared to that of Uzeba.

DISCUSSION

Legumes have the ability to form symbiotic association with micro-organisms; such as *Rhizobia* and vescicular arbuscular mycorrhizal (VAM) fungi. Mycorrhizal fungi have been reported to improve the growth and yield of leguminous plants, especially in phosphorus deficient soils as it enhances phosphorus uptake which was evident in this experiment (Zaidi et al. 2003). Pigeon pea directly influence soil quality, organic matter and soil environment as they are the determinant of the AMF networks development thereby influencing the soil (Hamel and Strullu, 2006., Poi et al. 1989). Pigeon pea and AM fungi inocula increase the pH of the soil to near neutral compared to initial soil pH of 5.9 and this resulted from the ability of the association to reduce the acidity of the soil. This was in accordance with the earlier work done by Heichel et al. (1991). The result also showed that pigeon and mycorrhizal fungi improve the carbon content of the soil and this was confirmed by the earlier work done by Drinkwater et al. (1998), they reported that legume base intercrop reduce carbon losses and increase the accumulation of carbon. Mycorrhizal fungi and pigeon pea association improve the soil nitrogen content. This result from the mutualistic interaction between mycorrhiza and rhizobia inhabiting the roots of pigeon pea which led to increase number of nodules formation and nitrogen fixation (Hodge, 2003). There was a synergistic interaction existing in the tripartite interaction of the Rhizobium-legume-AM fungi association (Gianinazzi-Pearson and Diem, 1982). Pigeon pea with mycorrhiza inoculation improved soil phosphorus concentration. This supports Rodrigues et al. (2003) findings that AM fungus can boost phosphorus uptake, plant development, and yield. Both cereals and legumes have been shown to benefit from arbuscular mycorrhizal fungi (Glomus clarum) in low-phosphorus soils. According to Rousseau et al. (1994), mycorrhizal hyphae can improve root nutrition absorption surface area. Soil nutrient concentration is increased by hyphae penetrating beyond nutrient deficient areas.

Table 1. Soil chemical and physical analytical results at Ekpoma and Uzeba site in 2008 and 2009

		Ekpoma			Uzeba		
Parameters	Units	Control (2008)	Pigeaon pea Plots (2009)	Pigeaon pea +Mycorrhiza plots (2009)	Control (2008)	Pigeaon pea Plots (2009)	Pigeaon pea +Mycorrhiza plots (2009)
pH(water 1:1)	-	5.95	6.10	6.20	5.92	6.00	6.10
Organic Matter	g /kg	15.50	21.90	28.70	9.60	10.60	11.90
Nitrogen	g / kg	9.00	11.40	27.00	0.90	5.70	8.00
Phosphorus	mg / kg	5.31	11.64	15.26	4.24	5.31	6.39
Potassium	cmol /kg	0.08	0.13	0.23	0.04	0.06	0.08
Magnesium	cmol /kg	0.37	2.13	2.73	0.33	0.71	1.97
Calcium	cmol / kg	0.67	4.32	5.31	0.49	1.86	3.45
Sodium	cmol / kg	0.10	0.31	0.37	0.09	0.28	0.38
ECEC	-	7.50	9.04	9.61	1.58	4.23	6.28
Base saturation	%	69.34	92.01	93.34	62.00	85.82	93.63
Sand	g / kg	832	834	854	904	906	901
Silt	g / kg	114	104	92	60	14	23
Clay	g / kg	54	62	54	36	80	76
Textural Class		Loamy sand	Loamy sand	Loamy sand	Sand	Sand	Sand

Table 2. Growth of maize and pigeon pea as affected by mycorrhiza in maize – pigeon pea hedgerow under field conditions at Ekpoma and Uzeba in 2008 and 2009 at twenty week after planting

Treatments	maize				Pigeon pea			
	Height (cm)		Stem girth (cm)		Height (cm)		Stem girth (cm)	
	2008	2009	2008	2009	2008	2009	2008	2009
AM +Sole PE					-	214.63^{a}	7.27^{a}	7.27a
AM+Sole PU					80.77	123.22	3.67	3.82
AM -Sole PE					185.42^{b}	218.09^{a}	6.42^{b}	7.38a
AM - SolePU					82.80	83.78	3.08	3.80
AM + MPintercropE	72.38^{a}	80.81^{a}	6.27^{a}	6.20^{a}	185.32^{b}	220.62^{a}	6.83^{b}	7.76a
AM+ MP intercropU	51.98	35.82	5.72	4.28	78.35	106.00	3.68	3.88
AM - MP intercrop E	62.37^{b}	68.26^{b}	5.20^{b}	5.60^{b}	172.40^{b}	218.22^{a}	6.30^{b}	7.02a
AM - MP intercrop U	46.77^{c}	39.84^{d}	5.43^{b}	4.16^{c}	72.53^{c}	99.33^{c}	3.03^{c}	3.53b
AM + Sole M E	70.02^{a}	70.02^{b}	6.43^{a}	5.87^{b}				
AM + Sole MU	49.72^{c}	35.15^{d}	5.75^{b}	4.00^{c}				
AM - Sole ME	64.98^{b}	50.69^{c}	5.43^{b}	5.18^{b}				
AM - Sole MU	43.23^{c}	31.97^{d}	5.72^{b}	3.73^{c}				

Mean values with the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range tests. AM+= with mycorrhizal inoculum; AM- = without mycorrhizal inoculum; intercrop MP= maize – pigeon pea hedgerow; sole m= sole maize; sole P= sole pigeon pea. E= Ekpoma, U= Uzeba.

Table 3. Yield (ton ha^{-1}) parameters of maize and pigeon pea as affected by mycorrhizal inoculum in maize – pigeon intercrop under field conditions at Ekpoma and Uzeba

Treatment	First planting season (2008)				Residual effect- second planting season (2009)				
	Maize		Pigeon pea		Maize		Pigeon pea		
	Yield	Shoot biomass	Yield	Shoot biomass	Yield	Shoot biomass	Yield	Shoot biomass	N_2 fixation
			1.65[a]	5.39[a]			2.58[a]	14.41[a]	
AM+Sole PE			1.01[b]	1.07[d]			1.23[b]	1.77[c]	
AM+Sole PU			0.25[a]	3.25[b]			1.55[b]	14.01[a]	
AM-Sole PE			0.17[b]	1.07[d]			0.85[c]	1.61[c]	
AM-Sole PU	2.24[a]	3.11[a]	0.18[b]	5.49[a]	2.65[a]	2.42[a]	2.36[a]	14.24[a]	0.15[b]
AM+MP intercropE	1.51[b]	2.02[c]	0.12[b]	0.96[d]	1.73[b]	1.82[c]	1.04[c]	1.12[c]	0.10[b]
AM+MP intercropU									
AM-MP intercropE	1.35[c]	2.81[b]	0.86[c]	2.74c	1.77[b]	2.27[a]	1.32[b]	12.38[b]	0.11[b]
AM-MP intercropU	0.77[d]	1.16[d]	0.46[c]	0.71[d]	1.34[b]	1.67[c]	0.77[c]	1.30[c]	0.09[c]
AM+SoleMaizeE	1.87[b]	2.51[b]			1.50[b]	1.66[b]			
AM+SoleMaizeU	1.45[b]	1.92[c]			1.08[b]	1.66[c]			
AM-SoleMaizeE	1.41[c]	1.89[c]			0.97[c]	1.51c			
AM-Sole MaizeU	0.65[d]	0.85[d]			0.35[c]	0.86[c]			

Mean followed by the same letter in the columns are not different at $P \leq 0.05$ according to Duncan's tests. AM+ = with mycorrhizal inoculum, AM - = without mycorrhizal inoculum, MP= intercrop maize- pigeon pea, Sole m= sole maize; sole P=sole pigeon pea, E= Ekpoma, U= Uzeba[1]SE=Standard Error.

Table 4. Nutrient uptake (kg ha^{-1}) of maize and pigeon pea as affected by mycorrhizal inoculum at Ekpoma and Uzeba under field condition

	EKPOMA						Uzeba					
TREATMENTS	SEASON 1: MAIZE			SEASON 2: MAIZE			SEASON 1: PIGEON PEA			SEASON 2: PIGEON PEA		
	N	P	K	N	P	K	N	P	K	N	P	K
AM + Sole PE							1,618.00^{a}	81.00^{a}	71.20^{a}	3,188.80^{a}	113.90^{a}	103.80^{a}
AM +SolePU							197.89^{e}	1.72^{d}	27.36^{c}	2,050.13^{b}	68.50^{b}	87.41^{b}
AM - Sole PE							864.50^{c}	62.00^{a}	52.40^{b}	3,478.76^{a}	100.90^{a}	105.80^{a}
AM + Sole PU							169.30	3.87^{d}	9.92^{d}	1,4214.36	51.24^{b}	43.92^{b}
AM +MPintercropE	301.00^{a}	31.00^{a}	10.50^{a}	609.30^{a}	46.50^{a}	32.40^{a}	1,213.70^{b}	55.00^{b}	56.60^{b}	3,310.90^{a}	105.40^{a}	116.70^{a}
AM +MPintercropU	126.40^{c}	2.13^{e}	3.81^{c}	168.18^{d}	6.81^{d}	5.88^{c}	417.75^{d}	5.47^{d}	7.64^{d}	1,992.53^{b}	77.13^{b}	59.99^{b}
AM –MpintercropE	241.20^{b}	17.00^{b}	9.50^{a}	490.50^{b}	23.90^{b}	21.80^{b}	652.50^{c}	33.00^{c}	54.80^{b}	3,449.80^{a}	118.90^{a}	94.10^{a}
AM-MPintercropU	92.85^{c}	1.77^{e}	3.80^{c}	95.58^{e}	2.08^{e}	4.56^{c}	566.60^{c}	2.06^{d}	8.30^{d}	1,681.36^{b}	70.14^{b}	60.12^{b}
AM + Sole ME	208.70^{b}	8.10^{d}	7.30^{b}	364.50^{c}	11.40^{d}	9.50^{c}						
AM + Sole MU	70.14^{c}	10.60^{c}	10.20^{a}	455.90^{b}	17.00^{c}	13.20^{b}						
AM-SoleME	60.12^{c}	8.10^{d}	7.50^{b}	374.50^{c}	11.40^{c}	9.50^{c}						
AM-SoleMU	25.46^{d}	2.10^{e}	1.24^{d}	26.05^{e}	5.69^{e}	1.25^{d}						

Mean followed by the same letter in the columns are not different at $P \leq 0.05$ according to Duncan's tests. AM+ = with mycorrhizal inoculum, AM - = without mycorrhizal inoculum, MP= intercrop maize- pigeon pea, Sole m= sole maize; sole P=sole pigeon pea, E= Ekpoma, U= Uzeba[1]SE=Standard error.

Compared to Uzeba's sandy soil, Ekpoma's sandy loam positively improves nutrient content and crop mycorrhiza use. Sylvia and Williams (1992) claim that sandy soils are more permeable, warmer, dryer, and less fertile than soils with finer texture, all of which affect AMF. This affects maize and pigeon pea growth and productivity. Inoculating maize and pigeon pea with mycorrhiza enhanced growth and yield. Mycorrhizal inoculum boosted the development and productivity of crops like maize and yam, according to Oyetunji et al. The results matched Ogungbe and Fagbola's (2008) findings that mycorrhiza improved maize growth and yield. Per Hamel (2003), inoculation of AM fungus promotes plant growth and development. The inoculation of mycorrhiza increased the dry matter weight of maize, as reported by Fagbola et al (1998). Intercropping increased maize yields significantly ($p \leq 0.05$) largely in the second cropping season. Intercrops improve future crops due to root and nodule senescence and leaf fall, according to Ledgard and Giller (1995). Danso (1992) and Gilleret al. (1994) demonstrated that leguminous crops can maintain soil fertility by fixing nitrogen and retaining green manure or residue. The lone non-mycorrhizal maize intercrop declined in yield as the mycorrhizal intercrop grew. The interaction of mycorrhizal fungi and rhizobia boosted the growth and yield of pigeon pea and maize in the intercrop. In 2009, the residual effects of maize-pigeon pea intercrop enhanced maize yield compared to solitary maize. After the first planting season, Egbe and Adeyemo (2006) and Egbe and Kalu (2009) found increased growth and production of maize intercropped with pigeon pea. Pigeon pea leaves litter boosted soil organic matter and nutritional status, enhancing maize and pigeon pea growth and productivity. Dania et al. (2009) found that using pigeon pea leaves/biomass as manure increased maize yield.

Inoculating pigeon pea with AM fungus improved N2 fixation. This verified Barea et al. (2002) findings that nitrogen-fixing rhizobia with mycorrhizal fungus boost pigeon pea nitrogen fixation. Inoculating plants with Mycorrhizal fungi and Rhizobial fungi improves nutrient uptake by plants (Hosamani et al. 2011).

Mycorrhizal fungus inoculation increased nitrogen absorption in maize compared to non-mycorrhizal maize ($p \leq 0.05$). Also, as shown by Fagbola et al. (2005), inoculating mycorrhiza to mycorrhizal crops improved nitrogen uptake. Inoculated intercropped maize and pigeon pea increased nutrient absorption compared to non-intercropped pigeon pea and single maize. From the texture and soil nutrient status, Ekpoma site showed considerably ($p \leq 0.05$) greater growth, yield, and nutrient uptake of maize and pigeon pea.

CONCLUSION

The comparative effects of legume - mycorrhizal base cropping system in Ekpoma and Uzeba was investigated. *Glomus clarum* and pigeon pea interaction increased soil nitrogen fixation, organic matter, and nutrient status. In Ekpoma, mycorrhizal fungus inoculation increased maize and pigeon pea yields in both solo and intercrop systems compared to Uzeba. Soil nutrient content influences mycorrhizal usage efficiency and plant nutrient absorption. The soil texture influenced the growth, yield, and nutrient uptake of maize and pigeon pea at both locations.

COMPETING INTERESTS

The authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

The raw data used to support the findings of this study are available from the corresponding author upon request.

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