Nigerian Journal of Soil Science 24 (2014) 183 – 190

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

EFFECTS OF MYCORRHIZAL INOCULATION AND CROP ROTATION ON MAIZE GROWTH AND BIOMASS PRODUCTION

AMUSAT, M.A[1], OSONUBI O[2], AND OYETUNJI, O.J[2]

[1]Dept. of Biology, Emmanuel Alayande College of Education, Oyo.

[2]Department of Botany, University of Ibadan, Ibadan

E-mail address: amusatbio2007@yahoo.com

Phone no: 08039194415

ABSTRACT

The research was carried out to investigate the effects of mycorrhizal inoculation and crop rotation on the growth and biomass production of maize. Maize as a staple food is grown in almost all part of the world but the threat to its sustainable production is declining soil nutrients. It had been reported that continuous use of chemical fertilizer has negative effects on ecological system and can not sustain crop production for long. Alternatively, incorporation of legume into maize based farming and inoculation with Arbuscular Mycorrhiza fungi combine with cultural agricultural system is a promising practice for sustainable maize production. The experimental design was a randomized complete block design in three replications comprising mycorrhizal inoculated and uninoculated, continuous and rotated maize treatment. The result showed that there was significant effect ($P = 0.05$) of mycorrhizal inoculation on growth and biomass production of maize in both continuous and rotated maize. The dry matter production of inoculated maize was between 6 – 43% higher than that of uninoculated counterpart. Similarly, there was effect of crop rotation on yield and biomass production of maize. The inoculation of maize with this microorganism combined with crop rotation can form part of agricultural practice in sub-Saharan African to ensure sustainable maize production.

INTRODUCTION

Sustainability in crop production is desirable in order to cater for ever increasing population growth which subsequently demands for more food production. Maize is one of the highly consumed cereal crops ranked the first in terms of production and third in terms of consumption among the ten staples that feed the World (Allianz, 2010; FAOSTAT, 2011) and therefore dominates agriculture in many regions of the World. Maize was introduced into Africa in 1500s and has since become one of Africa's dominant food crops and an important staple food for more than 1.2 billion people in sub-Saharan Africa and Latin America (IITA, 2012). The declining soil fertility is widely perceived and regarded as a major limitation to increasing yields, and a threat to sustainability of the maize based cropping systems (Nkhuzenje *et al*., 2002). The use of chemical fertilizer is one of the modern ways of improving soil fertility. However, its use had been proved to have two major shortcomings, which are the inability of small holder and resource poor farmers to procure the fertilizer and soil acidification (Juo *et al*., 1995). In addition it had been established that there is immobilization of some of the essential nutrients contained in the fertilizer to the form that could be utilized by plant.

According to Cassman and Pingali (1995), fertilizer alone cannot sustain plant yield for long periods. For example, in continuous rice or maize cropping with two to three crops grown annually, the use of N fertilizer increased with time but the yields often remained stagnant. This reflects a higher fertilizer requirement to produce the same yields, implying a decline in yield response to nutrients, possibly because of an over use of fertilizer. This calls for the use of alternative method through which crop production could be sustained without adverse ecological impact. The incorporation of soybean in maize cropping system will help supply nutrients especially nitrogen, which is critical in maize production (Nkhuzenje *et al.*, 2002).

Legumes-cereal rotation is practiced with the essence of making cereal benefit from the significant roles of legumes in maintaining soil fertility. If rotation is well selected among subsequent and succeeding crops, the soil fertility could be maintained with reducing dry matter weight and grain yield especially when leguminous crop was initially introduced to the soil. Legumes had been documented to reduce nitrogen fertilizer application of maize in a subsequent by 18 – 68kg/N/ha as compared to fallow (Petrickova, 1992), "Research shows that the most profitable rotation in the Corn Belt is the corn-soybean rotation". The nitrogen provided by soybean for growing maize is a major reason for this profitability (Iowa State University, 2004).

Arbuscular Mycorrhiza (AM) fungi are symbiotic, non pathogenic soil microorganisms recognized as soil biological resources in crop production which can increase nutrient uptake, particularly P, in nutrient deficient soil (Osonubi *et al*; 1991). Researchers (Dodd, 2000; Barea *et al.*, 2002; Gianinazzi et al., 2002; Jeffries et al., 2002; Ryan and Graham, 2002; Harrier and Watson, 2003) have reported that mycorrhiza help in improving soil quality and sustainable agriculture. The mycorrhizal role in maitainig soil structure is important in all ecosystems (Ryan and Graham, 2002). Mycorrhizal fungi contribute to soil structure by (1) growth of external hyphae into the soil to create a skeletal structure that holds soil particles together; (2) creation by external hyphae of conditions that are conducive for the formation of micro-aggregates;

Report on the use of microorganisms as biofertilizer shows that AM fungus plays vital roles in plant nutrients uptake. The most prominent among the nutrients is the phosphorous which, is generally regarded as the most important benefit that AMF provide to their host plant, and plant P status is often the main controlling factor in the plant-fungal relationship (Thompson, 1987; Smith and Read, 1997; Graham, 2000). AMF can play a significant role in crop P nutrition, increasing total uptake and in some cases P use efficiency (Koide *et al.*, 2000). This may be associated with increased growth and yield (Vosatka, 1995; Ibibijen *et al.*, 1996; Koide *et al.*, 2000).

However, there are some situations where crops fail to respond to colonization by native AMF, e.g. Ryan *et al.*, (2002), this is due to a high concentration of available soil P (Bethlenfalvay and Barea, 1994; Hetrick *et al.*, 1996. Where colonisation by AMF is disrupted, uptake of P, growth and in some cases yield can be significantly reduced (Thompson, 1987, 1991, 1994). Under such conditions, the colonization of roots by AMF is often suppressed (Jensen and Jakobsen, 1980; Al-Karaki and Clark, 1999; Kahiluoto *et al.*, 2001). Where strong AMF colonisation still occurs under conditions of h igh soil P concentration it may reduce crop growth (Gavito and Varela, 1995; Kahiluoto *et al.*, 2001).

The objectives of this research were therefore to investigate the effects of AM fungus inoculation on growth of maize and determine the impact of residual Nitrogen fixed by soybean (Glycine max) roots on biomass production and yield of maize through crop rotation.

MATERIALS AND METHODS

The experiment was conducted in the biological garden at Emmanuel Alayande College of Education, Oyo during the first cropping season between May/October of the year 2008 and 2009 respectively. In the first year soybean and maize were planted separately on different farmlands and were rotated the following year.

The species of AM fungus (*Glomus etunicatum)* used for the experiment was multiplied in the green house using maize as trapping host.

The early maturing maize TZSR (*Zea mays)* grains used for the experiment were obtained from International Institute of Tropical Agriculture (IITA) Ibadan. These were surface sterilized by immensing in 0.1% Mercury chloride for 5 minutes and then washed in several exchanges of distilled water. The root fragments of the host plant, soil and mixture of AM spores and hypha fragments were used as crude mycorrhizal fungi inoculums. The inoculation was carried out by placing 20g of the prepared crude inoculums directly into the planting hole underneath maize grains during planting and was later covered with the top soil.

The experimental design was a randomized complete block design in split plot with three (3) replications. These comprised of rotated and sole; mycorrhiza inoculated and uninoculated control treatments.

Two farmlands were used for the experiments; each farmland was 15 by 11 meter in size. Each farmland was divided into 3 blocks containing four plots which were 1m apart. The physico-chemical properties and nutrient analysis of soil were initially determined before planting (Table 1). The farmlands were ploughed and harrowed to facilitate growth. The two farmlands were planted with soybean and maize respectively in the first season while in the second season the two crops were rotated. The arrangement was a split plot with mycorrhizal and non-mycorrhizal inoculations. The maize was 40cm apart within row and 75cm between rows with two seeds per stand, giving a total population of 66.667 plant ha^{-1}. The plants were monitored for eight weeks after which they were allowed to complete their life cycle.

The plant height was measured, number of leaves and diameter of stem were determined for eight weeks at two week intervals.

At maturity, the plant was separated into leaves, stem and roots. The fresh weights of leaves, stems and roots were determined after which they were oven dried to constant weight at 70^oC for 2 days and dry weights were determined. The number of cob per plant and cob dry weights were also determined and the grain production was also measured.

Data obtained were subject to ANOVA and least significant differences (LSD) at 5% level of significance.

RESULTS

Table 1 below gives baseline information on the nutrient composition, pH, CEC etc of the soil used for the experiment before planting and after the harvest. This observed result from the pre-soil analysis may affect the nutrient status of the soil and further affect the development of the crops.

Table 1: Physical-chemical Properties of the Soil used for the Experiment

Sample	pH	%N	Av.P	%OC	%OM	Na	K	Ca	Mg	H^+	CEC	% Base saturation
A	6.50	0.06	11.46	0.48	0.83	0.13	0.16	1.28	0.04	0.085	1.695	94.99
B	6.76	0.11	16.92	1.08	1.56	0.31	1.14	0.16	0.38	0.085	1.695	93.96
C	6.52	0.06	9.82	0.57	0.83	0.12	1.16	0.15	0.03	0.082	1.69	92.48

A = The physical and chemical properties of the soil before the experiment.
B = The physical and chemical properties of the soil after the harvest of soybean
C = The physical and chemical properties of the soil after the rotated maize

Effects of mycorrhizal inoculation on growth of maize

Higher mean values of number of leaves and plant height were obtained in the mycorrhizal inoculated treatments in both sole and rotated maize (Figs 1 – 4). The number of leaves of the mycorrhizal inoculated treatment in both sole and rotated maize was 6.8% and 11.5% respectively higher than their uninoculated counterparts (Figs. 1 and 2). On the other hand the height of the mycorrhizal inoculated treatments was 6.0 and 7.3% higher than that of the uninoculated treatment Figs 3 and 4)

There was significant effect of mycorrhizal inoculation on dry matter production of both sole and rotated maize. Higher mean values of total dry weight (109.85±0.12) and cob dry weights (139.528.05) which were 6.0%, 16%, 11.5%, 42.7% and 31.1% respectively higher than their uninoculated counterparts were obtained in the sole maize. In the rotated maize however, the corresponding dry matter weights of mycrorrhizal inoculated treatments were 16.4%, 8.4%, 42.7% and 26.8% higher than their uninoculated counterparts (Table 2).

Table 2: Effects of Mycorrhizal inoculation on dry matter and biomass production of maize

Tmt	No of leaves	Plant height	Total dry wt (g)	Shoot dry wt. (g)	Leaf dry wt. (g)	No of cobs	Cob dry wt. (g)
			Soil Maize				
M^+	12.39±0.26	193.89±3.91	109.85±6.45	86.59±5.88	23.26±0.72	1.67±0.12	139.52±8.05
M^-	11.63±0.24	185.56±3.25	95.49±3.31	74.63±3.26	20.86±0.45	1.17±0.11	106.42±7.80
			Rotated Maize				
M^+	13.50±0.14	208.12±5.52	112.55±6.02	89.93±5.30	22.62±0.72	1.67±0.12	133.73±6.50
M^-	12.11±0.17	193.95±3.42	98.14±3.16	77.28±2.72	20.86±0.44	1.17±0.07	105.43±5.39
	*	*	*	*	ns	*	*

The values are means of three replicates ± = standard error
Ns = not significant, * = significant at P = 0.05 level of significant

M^+ = Mycorrhizal inoculated
M^- = Mycorrhizal uninoculated

There was effect of crop rotation on the growth of maize. The height of plant and number of leaves of rotated maize was 5.5% and 6.7% respectively higher than those of the sole maize (Table 3).

There were effects of crop rotation on biomass production of maize. The result obtained showed that there were significant differences in dry matter and biomass production between the sole and rotated maize. Higher significant mean values of shoot dry weight (83.61±4.01), leaf dry weight (21.74±0.58), number of cob (1.42±0.10) and cob dry weights (119.58±5.95) which were 20.51, 5.95, 16.39 and 9.20% respectively higher were obtained in the rotated maize compared with sole maize (Table 3).

Table 3: Effects of crop rotation on dry matter weight and biomass production of maize

Treatment	No of Leaves	Plant height	Shoot dry wt. (g)	Leaf dry wt. (g)	No of cobs	Cob dry wt. (g)
Sole	12.00±0.22	191.93±3.56	69.38±4.54	20.52±0.55	1.22±0.12	107.12±7.32
Rotated	12.81±0.16	201.93±4.47	83.61±4.01	21.74±0.58	1.42±0.10	119.58±5.95
Main Effect	ns	ns	*	ns	*	*
Cv %	6.75	5.51	20.51	5.95	16.39	11.63

The value are means of three replicates ± = standard error

Ns = not significant

Effects of Mycorrhizal inoculation on maize yield.

There was significant main effect of mycorrhizal inoculation on the yield of both sole and rotated maize. In sole maize, the yield of the mycorrhizal inoculated treatment was 544.44±12.85kg ha^{-1} which was higher than the yield obtained in the uninoculated counterpart (481.48±12.64kg ha^{-1}) while in the rotated maize the yield of the inoculated treatment was 646.44±13.05kg ha^{-1} which was 23.28% higher than the yield of the uninoculated treatment 524.84±13.05 (Table 4).

There was significant difference in yield between rotated and sole maize. Higher grain yield obtained in the rotated maize was 14.17% greater than that of sole maize (Table 5).

Table 4: Maize yield (Kgha^{-1}) as affected by mycorrhizal inoculation

Treatment	No of Leaves	Plant height
M^+	544.44±12.85	646.44±13.05
M^-	481.48±12.64	524.84±13.05
	*	*

Table 5: Comparison of maize yield in different systems of farming (kg ha^{-1})

Treatment	Yield	% Difference
Sole maize	512.96±29.29	
Rotated maize	585.64±29.29	14.17

DISCUSSION

Significant increase in number of maize leaves, plant height, total dry weight, number of cobs and cob dry weight between mycorrhizal and non-mycorrhizal inoculated treatments was due to positive effects of inoculation on maize. This may be attributed to symbiotic activities rhizosphere interaction of inoculated mycorrhiza with the rhizobium which led to nutrient mobilization. It has been reported (Merschner 1998) that one of the four major methods or mechanisms been adopted by plants to increase access to native or applied soil P in better symbiosis with soil microbes such as Arbuscular mycorrhizal fungi.

Significant biomass production and grain yield obtained in maize due to rotation may be attributed to the fact that maize has benefitted significantly from rotation due to transfer of residual nitrogen which had been fixed by the root of the soybean previously planted on the land. This in addition shows the effectiveness of the mycorrhizal strain used in the experiment.

The higher grain yield of maize obtained in mycorrhizal inoculated treatments showed that the microsymbiont used in the experiment was effective and its effectiveness contributed significantly to increase in maize production.

The result was in line with Joe *et al.* (1997) who submitted that there was a positive yield effect observed for both first year and annually rotated corn compared to continuous corn and that there was no significant negative effect of rotations compared to continuous corn. The result also correspond with that of Galleguillos *et al*., 2000) who observed large increases in yield of inoculated corn over un-inoculated controls and attributed this to rhizosphere interaction between AMF and beneficial rhizosphere microorganisms including free living N fixing bacteria and general plant growth promoting rhizobacteria (PGPR).

The significant differences obtained between mycrorrhizal inoculated maize and uninoculated maize further confirmed the efficacy of the AM fungus – *Glomus etunicatum* used for the experiment and the result is in line with the finding of the previous researchers that maize overshoot when inoculated with appropriate AMF.

The higher grain yield obtained in the rotated maize may be attributed to enhanced N availability in the experimental soil due the previously grown soybean i.e rotational effects. This makes the result to be in line with the reports of Sanginga *et al*., (2002) that the residual N benefits of promiscuous soybean to the subsequent cereal crop increase the crops yield better than sole corn.

Higher values of yield obtained in the rotated maize compared with the sole or continuous maize showed that rotation favoured biomass production and yield of maize than continuous cropping. The result was in line with Joe *et al.*, (1997) who attributed it to better environmental condition such as high but not excessive rainfall, temperature, solar radiation during the growing season and improved soil fertility.

Higher significant biomass and grain yield of maize reconfirmed that legumes preceeding maize provide sufficient N requirement to the succeeding maize crop. So soybean has residual effects and had contributed no matter how little to the growth, biomass and yield of maize.

However, rotation on the other hand is beneficial to farmer by improving soil fertility and it reduces cost of fertilizer application of the subsequent maize due to residual nitrogen fixed by soybean which eventually leads to increase in maize yield.

CONCLUSION

The fact that there was significant differences in growth, biomass production and yields between the inoculated maize and the corresponding uninoculated counterparts suggest alternative means of boosting crop production by resources poor farmers through procurement of less expensive plant growth booster such as rhizobium and mycorrhizal inoculants which have no negative ecological impact on ecosystem.

REFERENCES

Allianz "Food Security 2010: Ten Crop that feed the World". Allianz. http//knowledge.allianz.com/?709/food-crops.

Al-Karaki, G.N., Clark, R.B., 1999. Varied rates of mycorrhizal inoculums on growth and nutrient acquisition by barley grown with drought stress. J. Plant Nutr. 22, 1775-1784.

Barea, J.M., Azco'n, R., Azco'n-Aguilar, C., 2002. Mycorrhizosphere interactions to improve plant fitness and soil quality. Antonie van Leeuwenhoek 81, 343-351.

Bethlenfalvay, G.J., Barea, J.M., 1994. Mycorrhizae in sustainable agriculture. I. Effects on seed yield and soil aggregation. Am. J. Altern. Agric. 9, 157-161.

Cassman, K.G., and Pingali, P.L. 1995. Extrapolating trends from long-term experiments to farmers fields: The case of irrigated rice systems in Asia. Pp. 63-84. In: Agricultural Sustainability in Economic, Environmental and Statistical Terms, Barnett, V., R. Payne, and R. Steiner, (eds.) Wiley, London, pp. 63-84.

Dodd, J.C., 2000. The role of arbuscular mycorrhizal fungi in agro and natural ecosystems. Outlook Agric. 29, 55-62.

"FAOSTAT: Production-Crops 2010 data", 2011. Food and Agricultural Organization of the United Nations. http://faostat fao.org/site/567/DesktopDefault.aspx?PageIZ=567#ancor.

Gavito, M.E., Varela, L., 1995. Response of Criollo maize to single and mixed-species inocula of Arbuscular mycorrhizal fungi. Plant Soil 176, 101-105.

Gianinazzi, S., Schu'epp, H., Barea, J.M., Haselwandter, K. (Eds.) 2002. Mycorrhizal Technology in Agriculture – From Genes to Bioproducts. Birkha user Verlag, Basel.

Graham, J.H. 2000. Assessing cost of arbuscular mycorrhizal symbiosis in agroecosystems. In: Podila, G.K., Douds, Jr., D.D. (Eds.). Current Advances in Mycorrhizal Research. APS Press, St. Paul, NM, pp. 127-140.

Harrier, L.A. and Watson, C.A., 2003. The role of arbuscular mycorrhizal fungi in sustainable cropping systems. Adv. Agron. 79, 185-225.

Hetrick, B.A.D., Wilson, G.W.T., Todd, T.C. 1996. Mycorrhizal response in wheat cultivars, relationship to phosphorus. Can. J. Bot. 74, 19-25.

Ibibijen, J. Urquiaga, S., Ismaili, M., Alves, B.J., Boddey, R.M., 1996. Effect of arbuscular mycorrhizal fungi on growth, mineral nutrition and nitrogen fixation of three varieties of common beans (Phaseolus vulgaris). New Phytol. 134, 353-360.

IITA (2012). Research to Nourish Africa. International Institute of Tropical Agriculture Research report. 7-10.

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., Barea, J.M., 2002. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. Biol. Fertil. Soils 37, 1-16.

Jensen, A., Jakobsen, I., 1980. The occurence of vesicular-arbuscular mycorrhiza in barley and wheat grown in some Danish soils with different fertilizer treatments. Plant Soil 55, 403-414.

Joe L., Paul P. Oplinger 1997. The corn and soybean rotation effect. Field Crops 27. 426: 28, 426-14. http://corn.agronomy .wisc.edu

Kahiluoto, H., Ketoja, E., Vestberg, M., Seerela, I., 2001. Promotion of AM utilization through reduced P fertilization. 2, Field studies. Plant Soil 31, 65-79.

Koide, R.T., Goff, M.D., Dickie, I.A., 2000. Component growth efficiencies of mycorrhizal and non-mycorrhizal plants. New Phytol. 1148, 163-168.

Nkhuzenje H., Mughogho S.K., Sakala W.D. and Saka A.R. 2002. Contribution of Promiscous and specific Soybean Varieties to Soil Fertility improvement and maize yield for Smallholder Farmers in Zomba District of Malawi.

Osonubi, O.; Mulongoy K.; Awotoye O.O.; Atayese M.O.; Okali D.U. 1991. Effect of ectomycorrhizal and vesicular arbuscular mycorrhiza fungi on drought tolerance of four leguminous woody seedlings. Plant soil 136: 131-143.

Petrickova N. 1992. Interrelationship between fertilization and the composition of the crop rotation. Acta Acadamiae Agriculture ac Technicae Olstenensis Agricultural, 55: 41-47.

Ryan, M.H. and Graham, J.H., 2002. Is there a role for arbuscular mycorrhizal fungi in production agriculture? Plant Soil 244, 263-271.

Smith, S.E., Read, D.J., 1997. Mycorrhizal Symbiosis. Academic Press, London..

Thompson D.R. 1987. The effects of cereal heights in performance of stand intercropped with soybean. M.Sc Thesis, University of Daressalam, Morogoro, Tanzania.

Vosatka, M. 1995. Influence of inoculation with arbuscular mycorrhizal fungi on the growth and mycorrhizal infection of transplanted onion. Agric. Ecosyst. Environ. 53, 151-159.