MUARIK BULLETIN, Vol. 6. pp. 75-82, 2003
Printed in Uganda.
ISSN 1563-3721

The influence of arbuscular mycorrhizae fungus, mulch and fertiliser application on the yield of yams in an agroforestry system in southwestern Nigeria

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Abstract

The effects of chemical fertiliser and arbuscular mycorrhizae (AM) inoculation, and mulching on tuber yield of breeder selected cultivars and unselected landraces of *Dioscorea rotundata* Poir, and *Dioscorea alata* was studied in an agroforestry (Tungya) system. The field trials were conducted in three growing seasons (1996, 1997 and 1998) in the derived savanna zone of southwestern Nigeria. *Gliricidia sepium* trees served as live stakes for yams and source of mulch. The treatments comprised of AM inoculated (*Glomus mosseae*), non-inoculated, NPK fertiliser application, no-fertiliser applications and AM + fertiliser application. Mulching as a treatment factor was added in the third year. The results obtained in the first cropping year showed that both inorganic fertiliser and mycorrhizae applications improved tuber yield for the two selected yam species, with the response to fertiliser application being stronger. The unselected landraces did not respond to mycorrhizal and fertiliser application. In the second year, significant variations ($P \leq 0.05$) in tuber yields of all the cultivars were observed but all the three interventions increased yield relative to the control treatment. The third year experiments showed that unselected landrace yields were improved by a combination of mycorrhizal inoculation and fertiliser application and by mycorrhyizal inoculation alone but fertiliser application alone had no effect even on selected cultivars. In landrace 1, TDr93-2, and TDr93-31 yields were reduced by fertiliser application. The selected cultivars also responded to AM and fertiliser combined with AM applications. Contrary to expectations, mulching with *Gliricidia sepium* leaves in the agroforestry system had a detrimental effect on yam tuber yields. However, improved cultivar TDr93-2 had positive yield gains with application of mulch combined with AM inoculation.

Key words: Breeder-selected landrace, *Dioscorea alata, Dioscorea rotundata, Gliricidia sepium, Glomus mosseae*

Introduction

Tropical agriculture faces challenges of how to feed an ever increasing population and at the same time maintain long term sustainability in food supply without irreparably damaging of the natural resource base on which agricultural production depends (Ehui *et al.,* 1990). Inadequate food supply usually results from meager cultivation and/or poor harvest due to a declining resource base. The adoption of agroforestry land use system is probably one of the strategies that would ensure sustainable resource use. Agroforestry is one of the oldest agricultural systems. This concept aims at overall management of land by combining perennial trees with arable farming to control soil erosion, improve soil conditions, conserve soil and water to meet the needs of the people. The unique feature of agroforestry ecosystems is sustainability of natural resources during cultivation. In all ecosystems, rhizosphere biota act in support of plant growth and productivity in several ways. Mycorrhizae play crucial roles in linking plants and soils by transporting mineral elements to plants and carbon compounds to soil and its biota (Faber *et al.*, 1990; Osonubi *et al.*, 1992; Benthlenfalvay and Linderman, 1992; Fagbola *et al.*, *et al.*, 1998). Arbuscular fungi associated with the distal ends of fibrous roots fix soil nutrients especially phosphorus thereby enhancing plant growth.

Dioscorea rotundata (white yam) and *Dioscorea alata* (water yam) are major food crops grown by small-scale farmers, providing a staple carbohydrate source for a large population in the humid/ subhumid tropics. Production of yams is associated to agroforestry land use probably due to the factor that the crop derives support from the forest trees. It is an ancient crop in West and Central Africa (Coursey, 1967; Degras, 1993) and provides a promising avenue of alleviating the current food security and economic growth. Despite this great potential limited research has been done on agroforestry-related agronomic techniques in the recent past to improve yam cultivation in sub Sahara Africa (Ikeorgu *et al.*, 1995; Budelman, 1987; Ekanayake and Asiedu, 2002). Yam large-scale production and utilisation is constrained by high production cost, soil degradation and unavailability of suitable chemical fertilisers and herbicides.

Yam is a high nutrient-demanding crop grown immediately after fallow. It is a crop that develops poorly with low yields, in degraded soils compared to other tropical root crops such as cassava (*Manihot esculenta* Crantz) (Orkwor and Ekanayake, 1998). Monocropped yams also respond to fertiliser application particularly K in nutrient deficient soils and P (Olojede *et al.*, 2001). Response to the latter is probably due to the presence of mycorrhizal infections (Zaag-vander *et al.*, 1981). It is estimated that yams producing 30 t ha^{-1} tuber yield removed 107 kg N 14 kg P, 135 kg K, 2 kg Ca, and 7 kg Mg ha^{-1} (Norman *et al.*, 1984). Obigbesan *et al.* (1976) reported that *D. cayenensis* removed 140 kg N, 20 kg P, 182 kg K and 4-kg ha^{-1}. This reveals the need to devise mechanisms of replenising soils under yam cultivation. The objectives of this study were, therefore, to examine the role of improved agronomic interventions such as AM application, mulching and application of inorganic fertiliser on tuber yield of selected cultivars and locally adopted landraces of yams with a view to ensure sustainable resource use.

Materials and methods

Site description

The trials were conducted on established agroforestry plots at the Department of Botany and Microbiology research farm of the University of Ibadan situated in the derived savanna zone of southwestern Nigeria and located on 7°45'N and 13°9'E longitude with natural slope at 6%. The soil type is Rhodic Kandiustalf psammentic Haphistalf or Cambic Arenosol with low nutrient availability. The top soil was loamy sand, while the subsoil was coarse and fine textured clay loam mixture. The total rainfall ranged from 1200 mm to 1550 mm year^{-1} with total pan evaporation ranging from 1550 to 1650 mm year^{-1}. The mean solar radiation ranged from 12.5 to 25. 8 MJ m^{2}d^{1}. Average minimum temperature is usually between 20 and 24°C while the maximum temperature ranges between 30 and 34°C. The relative humidity was never below 40%. The fields had been planted with *Gliricidia sepium* (Jacq) Walp trees, which were scattered in a regular pattern. These multipurpose trees were planted in 1980s and maintained by regular pruning. The approximate density of trees was 2500 ha^{-1}. The trees served dual purposes; (i) as live *insitu* stakes for supporting multiple vines and (ii) as source of mulching material. The stakes served as the main treatment. The field used in the first and second year trials (same plot of land) was previously cropped with maize/cassava intercrop and sweetpotato *Ipomea batata* L.) in the last 6 years. Genotypes tested were TDr 131, TDr 93-2, TDr93-31 and Tda291 (i.e. 3 breeder selected cultivars of *D. rotundata* and 1 selected cultivar of *D. alata*, respectively and included 2 locally adopted landraces.

Experimental layout

The soil was cleared, loosened and heaped at 1 m x 1 m apart between the trees. Trials were set up in split-plot design of a randomised complete block design with 4 treatments and 3 replications. There were 6 blocks, 2 per replicate. Each block comprised of 4 plots while each plot consisted of 3 sub-plots. The 6 cultivars were randomly distributed within the plots. The treatments were randomised and replicated 3 times. The 2nd and 3rd season experimental designs were slightly modified based on the number of cultivars available. The agronomic intervention treatments were (a) AM (inoculated with *G. mosseae*), (b) fertilised (with NPK fertiliser basal application at rate 70 kg N, 30 kg P, and 20 kg K ha^{-1} (FPDD, 1990); c) AM + fertiliser, and (d) control (no AM or fertiliser). One yam set (seed yam tuber piece of > 250g each), per variety was planted in each heap. The inoculated plots received 20 g crude inoculum of *G. mosseae* (Nicholson and Gerdermann) Gerdermann and Trappe that was spread in each hole dug. The inoculum consisted of root fragments of the trap host, hyphae, soil and spores. Each yam set was placed in the hole before covering with soil. They were later mulched with 2 kg of fresh *Gliricidia* leaves. Thirty grams of NPK fertiliser was applied at 6 weeks after sprouting as fertiliser treatments. Due to inadequate seed material, landrace 2 and Tda291 were not included in the subsequent years. During the second year, all other treatments remained the same.

In the third year two additional treatments were added. These were mulch and mulch plus AM treatments. The experiments were conducted on another plot of land that was under fallow with *G. sepium* for 3 years. The trees were pruned regularly every four weeks and the biomass applied as mulch. Rate of application of mulch was 2 kg per heap at pruning. Weeding was carried out with a hand hoe every four weeks. No pest or disease infestations were observed. Harvesting was done at eight months after planting (MAP). The weights of tubers were taken and tuber yield per heap determined.The yield data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute, 1996).

Results

Results show that both the unselected landraces and breeders selected cultivar (TDr93-2) responded to AM inoculation and fertiliser application, and the combination of the two treatments (Table 1). In landrace 1, there was no fertiliser effect when compared to control *D. alata* accession (Tda291) which also responded to AM inoculation. TDr93-2 produced the highest tuber yields in all the treatments. However, the landraces produced higher tuber yield than TDr131 and TDr93-31. These last two cultivars did not respond to AM inoculation, and there was no significant difference ($P<0.05$) between their yields in AM inoculated and the control. The yields of TDr131 and 93-31 were significantly higher in plots treated with NPK fertiliser than those inoculated with AM fungus. But there were no significant differences ($P\leq0.05$) between fertilised and AM inoculated TDr-93-2 and landrace 2; while the landrace 1 treated with AM gave a significantly higher ($P\leq0.05$) yield than the fertilised one (Table 1).

In the second cropping season, the same cultivars gave significantly higher yields in AM, AM plus fertiliser, and NPK treatments (Table 1). There were significant variations in the yield of *D. rotundata* in the above three treatments. However, TDR-131 treated with AM and fertiliser showed no significant difference from the control. The fertilised TDR9302 also did not yield more than the control. There were general reductions in yields of the four cultivars in the second growing season. The only cultivar that yielded higher than those of the previous year was TDR93-31. It showed higher yields in all the treatments.

Table 2 shows the yield data obtained in the third year. The results in terms of response to agronomic treatments differed from those of the previous years. The yam plants responded to mycorrhizal inoculation and the combination of AM and fertiliser application. Applications of NPK fertiliser alone and mulching did not improve yields. Combined AM and fertilisation produced significantly higher tuber yields than the other treatments. However, these were not significantly different from the yields of the unselected landraces under AM treatment. The AM inoculated selected cultivars produced significantly less tuber weights than AM combined with fertilisation. The least yields were recorded in mulched plots.

Table 1. The influence of fertiliser and Glomus mosseae on fresh tuber yields of locally adopted landraces and breeder selected cultivars of D. rotundata and d. alata landrace (kg plant^{1}, 1996 and 1997 seasons).

Cultivars	Agronomic treatment				
	AM +Fertiliser	AM	Fertiliser	Control	Mean±s.e
			1996 season		
Landrace 1	3.86	3.64	2.80	2.79	3.27±0.19
Landrace 2	3.24	3.29	3.53	2.53	3.15±0.14
TDr 131	2.82	1.86	2.73	1.60	2.25±0.20
TDr 93 – 2	4.10	3.66	3.30	2.56	3.41±0.22
TDr 93 – 31	2.47	1.71	2.60	1.40	2.05±0.19
TDa 291	-	4.16	-	2.43	3.30±1.22
Mean±s.e	3.30±0.17	2.83±1.9	2.99±0.10	2.18±0.16	
			1997 season		
Landrace 1	2.73	3.25	3.25	4.35	2.79±0.39
TDr 131	1.56	0.94	1.09	0.81	2.67±0.47
TDr 93 – 2	2.51	1.55	1.59	2.23	2.48±0.47
TDr 93 – 31	4.35	0.81	1.59	2.23	1.6±0.20
Mean±s.e	2.75±0.24	1.10±0.11	1.97±0.16	3.72±0.33	

AM = inoculated with *Glomus mosseae*
Fertiliser = NPK fertiliser application
AM + Fertiliser = inoculated mycorrhiza plus NPK fertiliser application
Control = without mycorrhiza, fertiliser or mulch.

Table 2. The influence of fertiliser, mulch, and AM fungus on yam tuber yields of locally adopted landraces and breeder selected cultivars of D. rotundata (kg plant^{1}, 1998 season).

Cultivars	Agronomic treatment*						
	AM+fertiliser	AM+Mulch	AM	Fertiliser	Mulch	Control	Means±s.e
Landrace 1	3.89	1.58	3.49	1.45	0.98	2.00	2.23±
Landrace 2	3.87	1.77	3.95	2.83	0.54	2.11	2.15±
TDr 93 – 2	4.18	3.57	2.36	1.21	0.52	0.90	2.12±
TDr 93 – 31	3.65	0.91	2.19	0.56	0.47	0.72	1.41±
Means±s.e	3.90±0.07	1.96±0.38	3.0±0.29	1.51±0.32	0.63±0.08	1.43±0.24	

*AM = inoculated with *Glomus mosseae*
Fertiliser = NPK fertiliser application
AM + Fertiliser = inoculated mycorrhiza plus NPK fertiliser application
Control = without mycorrhiza, fertiliser or mulch.

Discussion

Effects of arbuscular mycorrhizae

The results indicate that inoculation of *Dioscorea* spp with AM is beneficial in agroforestry where yam tuber yield was enhanced by AM inoculation. Breeder selected cultivar TDr93-2 responded to either AM or NPK fertiliser. The two selected cultivars TDr131 and TDr93-31 relative to that of TDr93-2 were less amenable to AM inoculation in both 1998 and 1999 seasons illustrating genotypic differences in AM colonisation and suggesting that yam is a facultative host crop. Similar responses to AM inoculation in terms of genotypic differences had been reported for other crops (Ekanayake *et al.*, 2000; Oyetunji *et al.*, 2003). Due to lack of sufficient data, a comparison between *D. alata* and *D. rotundata* in agroforestry cannot be made in this study but would be a topic for future study.

Fertiliser application and sustainability issues

Reported literature on the response of yam to inorganic fertiliser application is mixed. Under monocrop situation yam yield increments of 15-35% due to NPK fertiliser has been reported in *D. alata* cv.Tda291 and *D. rotundata* cv. TDR 93-31, respectively (Adeniyi *et al.*, 2001). Earlier studies have reported depressive effect of the use of P fertiliser in P deficient soils (Anon., 1959). In soils with moderate P levels (7.3 mg kg^{-1} Bray 1 P), NPK fertiliser gave a 14% yield increase over the control (no fertiliser) in *D. rotundatai cv. TDr93-31* (Adeniyi *et al.*, 2001). Our results showed 71, 85 and 29% increases in yield over the control with fertiliser use for *D. rotundata cv.* TDr 131, TDr93-31 and TDr93-2, respectively. Although application of NPK fertiliser improved the tuber yield of *D. rotundata* yams in most instances, the increment was never significant over AM inoculation. This suggests that AM inoculation could be substituted for NPK fertiliser application in low P soils for yam production. The present investigation also revealed that combination of AM inoculation and NPK fertiliser greatly improved yam tuber yield but was comparable with AM inoculation alone for those genotypes with successful AM infestation. This observation confirmed the earlier findings of Gbedolo (1987) that application of chemical fertilisers has not always produced desirable positive results in yam. In fact, farmers in the region have indicated deleterious effects of NPK fertiliser on various aspects of tuber quality (Adeniyi, *et al.*, 2001). Such deleterious effects may partly be due to native mycorrhizae species interacting with fertiliser amendments.

Among the varieties tested, TDr93-3 was the only accession with an increment of yield in the second season of cultivation in the same land. The reduced yields of yam tubers in most genotypes in the second cropping season at same field site confirm reports that yams require high soil fertility maintenance, especially high soil organic matter build-up (Orkwor and Ekanayake, 1998). Our studies also showed that continuous cropping of yams for more than two growing seasons is not feasible unless nutrient amendments are done.

Effect of mulching

Application of mulch did not enhance yam tuber yields in this agroforestry system contrary to reports of positive effects of mulching during growth of sole cropped annual systems of yam (Okoli *et al.*, 1992; Osiru and Hahn, 1993). Nutrient depletion in general is a concern in alley cropping systems where hedgerow prunings are exported rather than used as mulch (Gichuru and Kang, 1996). Nutrient contribution efficiency of green manure or mulch is partly dependent on pruning management practices soil moisture and temperature and soil texture factors. Lack of positive contribution of mulching in the same year may be attributed to a low availability of essential nutrient while the role it plays in subsequent years may be unequivocal. The weed-suppressing role of mulch may not have been fully realised in the present study due to the hoe-weeding practice. The true value of mulch may have been in its favourable action on soil physical structure. Interestingly, the combination of AM and mulch application improved the yield over application of mulch alone. This observation further supports the importance of AM use as an agronomic intervention in yam cultivation. The negative effect of mulching with green biomass observed in the present study could lend support to the reason why the local farmers in the area usually remove the mulching materials after the establishment of yam. On the other hand, further application of mulch could be discouraged for socioeconomic reasons being a source of animal feed. The only occasion when a majority of farmers would mulch yam is immediately after planting the seed in a mound or heap particularly during the dry season (Ekanayake and Asiedu, 2002).

Combined effects of agronomic interventions on yam tuber yields

Aggregated benefit of the use of a single intervention versus combination of two treatments was not always positive and additive in all genotypes suggesting genotypic variation in their response. Only in cv. TDr131, did AM and NPK fertiliser combination produce an additive benefit (during both seasons). In general, it could be postulated that use of NPK fertiliser (particularly P element) and presence of AM are non-complementary to yam grown in low-P soils. The use of AM and fertiliser treatments, however, contributed between 15 and 75% more to tuber yield than the combination of AMD and mulching. At the same time, combining AM and mulching produced lower yields than when AM inoculation was used alone.

Conclusion

Among the three agronomic interventions in agroforestry, AM fungi inoculation enhanced more tuber yield than the other treatments followed by NPK fertiliser application. Mulching contributed the least and in some cases negatively affected the yam tuber yield in P-deficient soils. Our studies therefore indicate that inoculation of yam with AM fungus is important to enhance good tuber yields. In this low P soil, it can be postulated that the beneficial effect of AM is due to its fixation.

Acknowledgement

The authors are grateful to Dr. R. Asiedu; Coordinator of the yam project at the International Institute of Tropical Agriculture (IITA) who supplied the seed yam of the breeder selected yam cultivars. The unselected landraces were bought from DFFRI extension office, Oyo State, Nigeria. Additional logistical support was provided by IITA. The original inocula of AM species were supplied by Dr Pat Miller of USDA-ARS, Beltsville, USA.

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