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Assessment of Influence of Alley Cropping System and Arbuscular Mycorrhizal (AM) Fungi on Cassava Productivity in Derived Savanna Zone of Nigeria

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Abstract: The dearth of fertile 'virgin' land and inaccessibility to standard chemical fertilizers, coupled with low tuber yields has made cassava cultivation unprofitable in parts of traditional cassava zone of West Africa. Field experiments were conducted at Ajibode and Alabata villages located in Ibadan (derived savanna zone), Nigeria to evaluate cassava (*Manihot esculenta* Crantz) root yield response to alley cropping species and arbuscular mycorrhizae fungi (AMF) inoculations. On farm trials were conducted during two growing seasons, in Rhodic Kandiustalf soil type with low nutrients. The alley cropping systems used *Leuceana leucocephala* and *Senna siamea* as hedgerow tree species (main blocks), while AMF inoculation (with or without *Glomus clarum, G. mosseae,* or *G. fasciculatum*) served as the subplots. Improved cassava cvs. TMS 30572 and TMS 91934 were intercropped within alleys. The leaf dry weight and cassava tuber yield were greatly enhanced by AMF inoculation, whether alley-cropped or sole-cropped in Ajibode fields. The positive contribution of mycorrhizae to cassava root yield ranged from 20.7 to 39.3%, depending on the treatment combination. However, in Alabata fields, out of four farms, cassava yield was suppressed in three of the farms by hedgerow trees. The suppression in yield was between 138.9 and 2.7%. However, the combination of the multipurpose trees and AM fungi greatly enhanced the cassava root yield (between 20.6 and 166.7%) even more than AMF inoculation alone. It is concluded that alley cropping system can bring about sustainable cassava production in the derived savanna agroecological zone if integrated gith efficient AMF. Due to favourable factors it is desirable to encourage adoption of the above improved technologies by resource poor farmers.

Key words: Alley cropping % arbuscular mycorrhizal fungi (AMF) % hedgerow tree species % cassava % technology integration and tuberous roots yield

INTRODUCTION

Many African countries are experiencing acute food, environment and demographic crises due to inappropriate agricultural land management techniques. Tropical agriculture in the new millennium faces the challenge of how to feed an increasing population and at same time maintain long term sustainability in food supply without irreparably damaging the natural resource base on which agricultural production depends [1]. The problems of food production in the tropical regions of sub Saharan Africa are compounded by factors such as desert encroachment and bad agricultural policy.

Agroforestry is an age old agricultural system practiced in various parts of tropical Asia and Africa. The concept is aimed at the overall management of land by combining trees with food crops to control soil erosion, improve soil conditions and conserve soil and soil water to meet the needs of the crops as well as people. A unique feature of agroforestry that underlines sustainability is based on the use of nitrogen fixing potentials of leguminous species such as *Gliricidia sepium, Leeceana leucocephala, Acacia nilotica, Albizia lebbeck* which are planted as hedgerow trees [2].

In all ecosystems, rhizosphere organisms act in support of plant growth and productivity in several ways. Arbuscular mycorrhizal fungi (AMF) are one such soil organisms which play a crucial role in linking plants and soil, transporting mineral elements to plants and carbon compound to the soils and its biota [3-6] and are therefore important in tropical food crop based sustainable agriculture [5, 7].

Cassava (*Manihot esculenta* Crantz) is a tropical crop and has become one of the dominant starchy stables in humid lowlands of the tropics. Cassava is mainly cultivated in the savanna zone on small farms in varieties

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of infertile soils (without chemical fertilizer application) and in environments subjected to period of drought stress [8, 9]. It requires high rate of fertilization to produce maximum yield [10] Water stress reduces its net biomass production [11, 9] Cassava is highly mycotrophic. The improved cassava cultivars made available to farmers in the last two decades by the International Institute of Tropical Agriculture (IITA) have not been screened for mycorrhizal dependency, although, recent studies indicate potential use of the degree of AMF colonization and clonal responsiveness as useful selection criterion in cassava breeding [12, 7]. It was important to identify which of the improved cassava cultivars are highly responsive to AM fungi inoculation under tropical environmental conditions in the derived Savanna zone of Nigeria and under on-farm test conditions. This study was also used to examine the competitiveness of natural versus artificial incoculation of *Glomus.* spp. as is faced under *in situ* conditions in cassava fields. The study was furthermore aimed at investigating the influence of multipurpose trees on sustainable production of cassava in the sub-humid ecosystem.

MATERIALS AND METHODS

The field trials were set up at Ajibode and Alabata villages in Ibadan, Oyo State, Nigeria. These villages are in the derived savanna or transition zone between rainforest and humid savanna zones (Latitude 7°34^{1}N and Longitude 13°9^{1}E). The relative humidity in the field sites was high (minimum 61% and maximum 83%). Pan A evaporation ranged from 1550-1600mm (mean annual).

The experiments were conducted in already established alley cropping fields. Soils were nutrient depleted after long periods of cropping and of Rhodic Kandiustalf type. At Alabata, the fields were between 6 and 9 years of fallow periods when the experiments were set up. The Ajibode field was established in 1990 after a long period of continuous cropping with various crops such as melon, maize, pepper, cocoyam and cassava. The field was still under continuous cropping when the alley cropping system was established. The sole cropped plot was under fallow for about three years when these experiments started. The alley cropping plots in Ajibode village were inoculated in 1990 and 1991 with *G. clarum* while the Alabata village fields were not inoculated until the commencement of the experiment in the year 2000.

The hedgerow trees at Ajibode were *Leuceana leucocephala, Senna siamea* and their mixture. These served as the main blocks. Each block was divided into two sub-blocks and two test cassava cultivars were interplanted with the trees within each plot. Each plot was further split into two for AMF treatment. The cassava plants were either inoculated with *G. clarum* or not. This served as the sub-plot. All these factors were arranged in split plots, which were randomized in a complete block design. The second field at Ajibode was designed in the same manner except that *Gliricidia sepium* was used to replace the mixture mentioned above and AM species *G. mosseae* was used instead of *G. clarum*. The above treatment design was slightly modified at the Alabata village field trial. Similar to Ajibode, the hedgerow trees were *L. leucocephala* and *Senna siamea*. They were however not interplanted (mixed). For cassava cultivar treatment, due to planting material limitation only TMS 30572 was used while *G. fasciculatum* was used to inoculate the cassava stem cuttings used at planting. The AM inoculation was done by applying 20 g inoculum (which consisted of soil, trap host root fragments, hyphae and spores) under the cassava stake before covering with soil.

The hedgerow trees were planted 25 cm apart within the row that was 12 m long. The trees were spaced 6m apart in width in each plot. There were 2 m gaps between each plot within the rows. The plots were 8 m apart. Cassava was planted 1 m^2 apart. Each plot was 12 x 6 m^2. Each treatment was replicated three times in all experiments.

The hedgerow trees were pruned every two months and the fresh pruning biomass was applied thereafter to the associated food crops as mulch. The cassava plants were harvested at 12 months after planting (MAP) and tuberous roots were analyzed further. The tuberous roots and leaf samples were chopped into small pieces and then oven dried for 72 hours at 70°C and weighed. These data were used for dry biomass yield calculations.

The percentage mycorrhizal colonization rates of the fibrous roots of cassava were determined by collecting fine root segments (about 2 g) from each harvested cassava plant within each plot. They were stored in 50% ethanol until further analysis. The fibrous roots were later cleared in 10% KOH by soaking in the solution overnight. Roots were further bleached in alkaline H_20_2 and afterwards rinsed thoroughly in running water. The bleached roots were soaked in 1% HCl for 30 min. After this step, the roots were stained in 0.05% Trypan blue in 500ml of glycerol, 450ml of water and 50 ml of HCl. The percentage root infection was then determined by grid line intersects method of [13].

All crop data were analyzed using fixed model analysis of variance (ANOVA) for individual experiment using the windows version of Statistical Analysis System

(SAS) package (SAS, 1991). The treatment means were separated with Duncan multiple Range Test (DMRT) for significant variables.

RESULTS

The percentage root colonization of cassava fibrous roots by AM fungi at Ajibode field trial is shown in Tables 1a and 1b. The results show that cassava fibrous roots were all colonized by AMF, whether inoculated or not inoculated. However, those inoculated plants with *G. clarum* were more colonized than the non-inoculated cassava. There was also higher fibrous root colonization observed in alley cropped cassava particularly those roots grown under *L. leucocephala* trees had the highest root colonization (Tables 1a and 1b).

Table 2 shows the biomass production of TMS 91934 when inoculated with *G. clarum* under the multipurpose trees at Ajibode village. The leaf production of this cultivar was higher in *G. clarum* inoculated plots than what was observed in the non-inoculated plots. The least leaf production of cassava was recorded under non-inoculated *S. siamea*. The tuber yield was generally higher in inoculated TMS 91934 than in non-inoculated ones (Table 2). Although, the highest tuberous root yield was recorded in the interplanted *Senna* and *Leuceana*, but not significantly different from those of non-interplanted *L. leucocephala* and *S. siamea*. However, the root yield in the sole plots was similar to those mentioned above.

Similar trend of results as TMS 91934 was also observed for the biomass production of TMS 30572 when

Table 1a: The percentage fibrous r oot colonization of two cassava cultivars under the hedgerow trees by arbuscular mycorrhisal fungi at 12 months after planting at Ajibode (first growing season)

	TMS 30572		TMS 91934	
Hedgerow Treatment	Mycorrhizal Inoculated	Mycorrhizal Non-inoculated	Mycorrhizal Inoculated	Mycorrhizal Non-inoculated
Mixture of species	69.80a	35.77b	72.48a	40.65b
L. leucocephala	75.33a	38.67b	74.17a	38.77b
S. siamea	56.53a	23.55b	59.80a	25.86b
Sole Cropping	77.65a	36.15b	72.67a	33.33b
Significance of F statistic (ANOVA				
Treatment	ns	ns	ns	ns
MI	nd	***	nd	***
Treatment * MI	*	*	*	*

The means are values of three replicates. Means followed by the same letter in a row within each cassava cultivars are not significant different at P = 0.05. *** P<0.001; * P<0.05; ns not significant; and nd: not determined

Mixture: *L. leucocephala + S. siamea;* Sole: without hedgerow trees; MI: mycorrhizal inoculation

Table 1b: The percentage root colonization of two cassava cultivars under the hedgerow trees by arbuscular mycorrhizal fungi at 12 months after planting at Alabata village

	1st Season			2nd Season	
Hedgerow Treatment	Mycorrhizal Inoculated	Mycorrhizal Non-inoculated	Treatment	Mycorrhizal Inoculated	Mycorrhizal Non-inoculated
Farm 1			Farm 3		
L. leucocephala	97.2a	51.8b	L. leucocephala	96.7a	63.6b
Sole	74.9a	48.6b	Sole	84.3a	44.8b
Farm 2			Farm 4		
L. leucocephala	98.4a	62.7b	L. leucocephala	91.9a	37.5a
S. siamea	93.5a	59.9b	S. siamea	86.1a	41.6b
Sole	95.5a	53.8b	Sole	83.3a	45.2b
Significance of F Statistic (ANOVA)					
Treatment	ns	*		*	*
MI	nd	***		nd	***
Treatment * MI	nd	**		nd	***

The means are values of three replicates. Means followed by the same letter in a row within each farm are not significantly different at P = 0.05. *** P<0.001; *<0.05; ns not significant; nd: not determined

Sole: without hedgerow trees; MI: mycorrhizal inoculation

Table 2: Biomass (t/ha) production of cassava cv. TMS 91934 under G. clarum inoculation and hedgerow trees at Ajibode village (first growing season)

Hedgerow Treatment	Mycorrhizal Inoculation	Mean Leaf Dry Weight	Mean Tuberous Root Dry Weight
L. leucocephala	Inoculated	2.57a	6.9a
	Non-inoculated	1.93ab	4.17bc
Mixture of species	Inoculated	2.6a	7.5a
	Non-inoculated	1.87ab	4.18bc
S. siamea	Inoculated	2.0ab	5.4ab
	Non-inoculated	1.4b	3.2c
Sole	Inoculated	2.37ab	6.0a
	Non-inoculated	1.8ab	3.67c
Significance of F Statistical (ANOVA)			
Treatment		**	***
MI		*	***
Treatment * MI		*	***

The means are values of three replicates. Means followed by the same letter in a column are not significantly different at P=0.05. ***P<0.001; ** P<0.01; and * P<0.05

Mixture: *L. leucocephala + S. siamea;* Sole: without hedgerow trees; and MI: mycorrhizal inoculation

Table 3: TMS 30572 biomass (t/ha) production under G. clarum inoculation and hedgerow trees at Ajibode village (first growing season)

Hedgerow Treatment	Mycorrhizal Inoculation	Mean Leaf Dry Weight	Mean Tuberous Root Dry Weight
L. leucocephala	Inoculated	2.39a	6.54a
	Non-inoculated	1.74ab	3.85b
Mixture	Inoculated	2.23a	5.82a
	Non-inoculated	1.61b	3.90b
S. siamea	Inoculated	1.70b	4.30b
	Non-inoculated	1.02b	2.45c
Sole	Inoculated	2.08a	4.95ab
	Non-inoculated	1.69b	3.68bc
Significance of F Statistical (ANOVA)			
Treatment		*	**
MI		**	**
Treatment * MI		*	***

The means are values of three replicates. Means followed by the same letter in a column are not significantly different at P=0.05. ***P<0.001; ** P<0.01; and * P<0.05

Mixture: *L. leucocephala + S. siamea;* Sole: without hedgerow trees; and MI: mycorrhizal inoculation

inoculated with *G. clarum* at Ajibode (Table 3). Its tuber yield was generally higher in the inoculated plots than the non-inoculated plots. The influence of the hedgerow trees on TMS 30572 root yield response was similar to those of TMS 91934.

The influence of another AM fungus species (*G. mosseae*) was tested on TMS 30572 in a different field at the Ajibode village in second growing season (Table 4). The cassava leaf production was significantly higher in mycorrhizal inoculated plots than the non-inoculated counterparts. The lowest leaf production was exhibited by the non-inoculated cassava plants interplanted with *S. siamea*. Except for inoculated and non-inoculated cassava under *S. siamea*, cassava tuber yield was higher in inoculated alley-cropped and sole-cropped cassava than their non-inoculated counterparts.

The similar tuber yield under *S. siamea* was observed despite the significant differences in their leaf dry weights (Table 4).

When *G. fasciculatum* AM fungus was used for inoculation of cassava at Alabata village the cassava tuberous root yields were higher in the sole plots than under the hedgerow trees (Table 5). This relatively poor situation with regard to the performance of cassava was not different even in the AMF inoculated alley plots.

Table 4: The influence of G. mosseae on fresh biomass production (t/ha) of cassava cv. TMS 30572 under hedgerow trees at Ajibode village (second growing season)

Hedgerow Treatment	Mycorrhizal Inoculation	Mean Leaf Dry Weight	Mean Tuberous Root Dry Weight
L. leucocephala	Inoculated	15.6a	33.6b
	Non-inoculated	11.7b	21.9c
G. sepium	Inoculated	12.74ab	44.5a
	Non-inoculated	9.10bc	24.02c
S. siamea	Inoculated	14.65a	20.1c
	Non-inoculated	7.97c	20.2c
Sole	Inoculated	15.11a	36.6a
	Non-inoculated	10.3b	21.04c
Significance of F Statistical (ANOVA)			
Treatment		*	**
MI		***	***
Treatment * MI		ns	*

The means are values of three replicates. Means followed by the same letter in a column are not significantly different at P=0.05. ***P<0.001; ** P<0.01; and * P<0.05; ns: not significant

Sole: without hedgerow trees; and MI: mycorrhizal inoculation

Table 5: The influence of G. fasciculatum and hedgerow trees on cassava (TMS 30572) fresh tuberous root yield (t/ha) at Alabata (Means ± std. Errors), (first growing season)

	Fresh tuberous root yield (t/ha)	
Hedgerow Treatment	Mycorrhizal Inoculated	Non-Mycorrhizal Inoculated
Farm 3		
L. leucocephala	15.5 ± 1.82	10.0 ± 3.99
Control	23.0 ± 2.09	14.6 ± 2.13
Farm 4		
L. leucocephala	21.9 ± 0.9	8.2 ± 2.55
S. siamea	15.0 ± 0.95	12.5 ± 1.34
Control	22.31 ± 3.01	16.0 ± 0.62
Significance of F Statistic (ANOVA)		
Treatment	**	***
MI	nd	***
Treatment*MI	nd	***

The means are values of three replicates. *** P<0.001; ** P<0.01; nd: not determined

Sole: without hedgerow trees; MI: mycorrhizal inoculation

Table 6: The influence of G. fasciculatum and hedgerow trees on TMS 30572 fresh tuberous root yield (t/ha) at Alabata (Means ± std. Errors), second growing season

	Fresh tuberous root yield (t/ha)	
Hedgerow Treatment	Mycorrhizal Inoculated	Non-Mycorrhizal Inoculated
Farm 1		
L. leucocephala	25.0 ± 5.53	19.2 ± 4.21
Sole	14.7 ± 1.98	12.2 ± 1.59
Farm 2		
L. leucocephala	6.3 ± 0.03	4.3 ± 0.05
S. siamea	7.74 ± 0.23	3.9 ± 0.09
Sole	7.5 ± 027	9.2 ± 0.07
Significance of F Statistic (ANOVA)		
Treatment	*	**
MI	nd	***
Treatment*MI	nd	*

The means are values of three replicates. *** P<0.001; ** P<0.01; * P<0.05; nd: not determined

Sole: without hedgerow trees; MI: mycorrhizal inoculation

However, application of the AM fungus brought about higher yield in sole plots. Table 6 shows the results obtained in other alley cropping trials at the Alabata village. The sole cropped cassava in this site also recorded the highest tuberous root yield in one of the trials under both mycorrhizal treatments. The presence of multipurpose trees nonetheless was able to enhance the cassava yield more than in the sole plots in the other trial in Alabata.

Accordingly cassava tuberous root yields were greatly reduced by alley cropping system in three out of the four fields investigated at Alabata (Tables 5 and 6). The percentage reduction in tuberous root yield ranged from –139 to –2%. Among the hedgerow species, *S. siamea* was the worst in this regard. However, AM fungi inoculations irrespective of the species *(G. clarum, G. fasciculatum* and *G. mosseae)* greatly enhanced cassava tuberous roots yields in all the fields. The enhancement was more when it was combined with the hedgerows trees. The increase in cassava yields brought about by the AM fungi ranged between 20.6-167%.

DISCUSSION

The results obtained in this study indicated that the cassava fibrous roots were heavily infected with AM fungi irrespective of the inoculation treatment of the planting material confirming previous reports on the affectation of cassava to AMF [6, 15, 16]. AM fungi such as *Glomus* spp. and *Acaulospora* spp. were found to be present in all the plots and were also proved effective on all plant species. This suggests that the soils (at both test villages in derived savanna zone) were infested with native AM fungi and that they were efficient in colonizing cassava fibrous roots. The results also revealed that the introduction of exotic AM fungi species could bring about an overwhelming increase in cassava tuberous root production over and above the effect of native AM species [17, 18, 7]. That they enhanced the productivity level of cassava under alley cropping system laid credence to the fact that they are enhancing agents of transportation of mineral nutrient from the soil to the plants while acting as links between soil and plants. Furthermore, they could be influenced to perform better when the physical and chemical soil characteristics (features) are improved. They transfer the nutrients released by the decomposing leguminous hedgerow tree leaves and root nodules to the cassava.

The reductions in the cassava tuberous root yield brought about by the alley cropping system (contrary to the findings of [6, 16]) might be due to a number of reasons. The difference might be due to the ages of the multipurpose trees used by us versus the previous mentioned workers. The former workers worked with hedgerow trees that were not as old as the ones used in this study. The hedgerow trees had an advantage over cassava because they were well established and had developed deeper and denser rooting systems. Second, the shading effects of the tree canopies on cassava (i.e. above ground competitions) especially at active vegetative growth phase could also be responsible for the reduction obtained. Therefore both below ground and above ground competition between trees and the associated arable crops might be responsible for the observed negative effect. Among the hedgerow species there was a difference in such competitiveness. The case of *Senna* that appeared to be the worst might be due to the fact that it is a non-nodulating legume coupled with the fact that its lignin content of biomass was higher than that of *Leuceana*. These factors slow down decomposition rates of its leaves [19] and thereby produce biomass quality differences.

The combination of the AM fungi and the hedgerow trees enhanced cassava tuberous root production more than AMF inoculation alone [7]. It could also be due to numerous reasons. The trees may improve the soil physical conditions for mycorrhizae to perform better. The release of nitrogen from the nodules of the multipurpose trees may enhance the efficiency of mycorrhizae. The indication according to our study is that the mycorrhizae made available more nutrients to the cassava roots in alley cropping, hence its higher productivity.

The effectiveness of AMF in alley cropping system in these experiments might be due to (1) effective utilization of nutrient released from the pruning decomposition, (2) positive tripartite association, i.e. AM – Rhizobium – legume crop association and that *Senna* could not appreciably increase cassava yield and (3) pruning application improved soil physical and chemical structures that in turn influenced soil fauna and flora performance.

Above findings from our hedgerow-cassava-AMF experiments suggest that agroforestry with mycorrhizal integration could go a long way in enhancing sustainable production of cassava with little or no chemical fertilizer application. The integration of multipurpose trees and AMF if appropriately applied can solve some ecological problems (such as damaging of the natural resource base upon which agricultural production is based) confronting food production is sub-Saharan Africa. The trees replenish the soil nutrients and improve physico-chemical properties of the soil while mycorrhizae transport the nutrients (particularly phosphorus) to the associated arable crops.

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