

REGULAR ARTICLE

INTERPLAY BETWEEN ARBUSCULAR MYCORRHIZAL FUNGI AND POULTRY MANURE ON GROWTH AND YIELD OF SOYBEAN (*GLYCINE MAX* (L) MERILL) UNDER SCREENHOUSE CONDITIONS

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ABSTRACT

A pot experiment was carried out at the University of Ibadan, Oyo State Nigeria using the Completely randomized design to study the growth of soybean (*Glycine max* L.) as affected by mycorrhizal species and poultry manure interplay under screenhouse conditions. The treatments include five levels of mycorrhizal inoculum, and two levels of poultry manure. Data collected include plant height, number of leaves, number of branches, leaf area and biomass yield. Analysis of variance was carried out on all data and means were separated using the Duncan's multiple range test at $p < 0.05$. *Glomus gigaspora* with 12.5 g poultry manure, *Glomus gigaspora* with sole 6.25 g poultry manure significantly enhanced the growth of soybean. Fresh and dry biomass of soybean were also significantly enhanced by *Glomus deserticola* with 12.5 g poultry manure. Number of seeds / pot and grain yield/pot were significantly enhanced when compared with the control. Mycorrhizal spore count in the soil at harvest were significantly different with highest spore observed under *Glomus clarum* and the least under control. This study concludes that mycorrhizal species-poultry manure combination varies in their effect on the growth and yield of soybean.

Keywords: Arbuscular mycorrhiza fungi, plant growth promotion, principal component analysis, Soybean, sustainable agriculture, yield

INTRODUCTION

Soybean (*Glycine max* L.) is a leguminous crop. It belongs to the family *Fabaceae*, subfamily *Papilionoideae*, genus *Glycine* and subgenus *soya*. It is an herbaceous annual plant which is one of the world's most valuable crop used as a source of dietary protein (Park *et al.*, 2020). Tropical Soybean varieties can be categorized into three groups based on the maturity period. Early maturing which matures in less than 105 days after planting, medium maturing which matures between 105-120 days after planting and late maturing which mature after 120 days after planting. The present production of this crop and many other crops are not adequate to meet the growing world population. Climate change and urbanization are the two major factors affecting food production (Borrell *et al.*, 2020). Conventional farming cannot achieve the production of enough food if the population continues to increase at this pace hence, the need to find better and suitable means of food production so that enough food can be made available. Consequently, the use of organic agriculture and plant growth promoting microorganisms (PGPM) has been adopted.

Organic agriculture is important in achieving food security (Muller *et al.*, 2017) and it is regarded as being environmentally friendly than conventional agriculture (Meemken and Qaim, 2018). Application of organic residues to soils increase soil organic matter, buffer soil, improve aggregate stability and enhance water retention capacity of soils. Organic agriculture is environmentally friendly and excludes use of inorganic fertilizer. Manure has been used effectively as organic fertilizer for centuries and their nutrient content varies depending on source and nutrient content (Reganold and Wachter 2016; Zhang *et al.*, 2020) organic manures are efficient in increasing soil nutrient contents, ensuring positive residual effects and enhancing soil's physical and chemical characteristics (Mahmood *et al.*, 2017). The utilization of the inorganic manure is an integral part of agriculture that has been exploited overtime and across ages because of its ability to restore soil fertility, supply major plant nutrients, such as N, P, K, Ca, Mg and stabilizes soil pH.

The PGPM are majorly of bacteria and fungi microbes. They have been successfully implemented in the promotion of growth in various plants (Igiehon *et al.*, 2020; Olanrewaju and Babalola, 2019). Different mechanisms such as growth hormone production, siderophore production, nitrogen fixation, phosphorus solubilization, ACC deaminase production, etc. are employed by PGPMs in improving plant growth and controlling pathogens (Olanrewaju *et al.*, 2017).

One major fungus that has been implemented in plant growth promotion is Arbuscular mycorrhizal fungi (AMF). Many agricultural and horticultural crop species form a mutualistic symbiotic relationship with AMF in their roots (Igiehon and Babalola, 2017). AMF are efficient in acquisition of nutrients resulting in improved plant growth (Kim *et al.*, 2017; Liang *et al.*, 2019).

Furthermore, root colonization with AMF enhances plant tolerance to abiotic stress (Al-Arjani *et al.*, 2020; Begum, Ahanger, *et al.*, 2019; Begum, Qin, *et al.*, 2019; Mathur *et al.*, 2018; Yasmeen *et al.*, 2019), thus improving crop growth and productivity. AMF are of immense importance in maintaining soil fertility which are influenced by the effect of climatic and seasonal changes on the physical and chemical properties of soil.

The objective of the study therefore is to know the effect of selected AMF and poultry manure on growth, yield, and nutrients uptake of soybean under screenhouse conditions.

MATERIALS AND METHODS

Soil collection and analysis

The experimental soil was collected on the agricultural land site of the University of Ibadan, Nigeria (7°24'N; 3°48'E) and pot experiment conducted in the screenhouse of the Department of Agronomy, University of Ibadan, Ibadan, Nigeria. Soil sample was collected at a depth of 0-15 cm, air-dried and sieved with 5 mm mesh size to remove debris before weighing into 5 kg pots. The bulk soil was sub-sampled, air dried at room temperature and grounded to pass through 2 mm and 0.5mm diameter sieve for analysis. The particle size analysis was done by hydrometer method (Gee and Or, 2002). The pH was determined in a 1:2 soil/water suspension using digital pH meter. Organic carbon was determined by Walkley-Black dichromate wet oxidation method (Nelson and Sommers, 1996). Total nitrogen was by micro-Kjeldahl distillation technique as described by Bremner and Mulvaney (1982). Available phosphorus was determined by Bray No 1 method as described by IITA (1982). Exchangeable K, Ca and Mg were extracted using ammonium acetate, K was determined using flame photometer, Ca and Mg determined using atomic absorption spectrophotometer.

Poultry manure preparation

Poultry manure was air-dried and characterized by nitric and sulfuric acids before further analysis to determine the micronutrients following standard protocols (Cater; Kalra and Maynard, 1991).

Mycorrhiza source

Sample of mycorrhiza propagules was collected from Soil Microbiology Laboratory of the Department of Agronomy, University of Ibadan, Nigeria. They are *Glomus clarum* (G.c), *Glomus gigaspora* (G.g), *Glomus deserticola* (G.d), and *Glomus mosseae* (G.m). Arbuscular mycorrhizal inocula (20 g each) were applied at third-quarter central top of the soil 24 hours before soybean seed were sown into the soil (Carling *et al.*, 1978).

Experimental design and treatments

The experimental was a factorial with mycorrhiza having five levels, poultry manure with three levels of poultry manure viz 6.25 g (1 pm), 12.5 g (2 pm) and a control. The experiment was arranged in a completely randomized design and replicated three times to give a total of 45 pots. The variety of soybean planted was (TGX 1448 -2E). Two soybean seed were sown in 5 kg pot filled with topsoil. The mycorrhiza inoculum was applied alone, and the two levels of poultry manure were also applied alone after which each inoculum was applied in consortia with each level of poultry manure. There was a control in which nothing was applied. Standard agronomic practices were followed.

Statistical analyses

All data were analyzed using analysis of variance (ANOVA) with the statistical analysis software (SAS) version 9.4 (SAS Institute, Inc., Cary, NC, USA), and Duncan's Multiple Range Test (DMRT) at $P < 0.05$ was used to separate the means. Multivariate analysis was done using the R statistical package (**R Core Team, 2019**). Principal component analysis (PCA) was done using the FactoMineR package (**Lê et al., 2008**) and Pearson correlation was performed using the core function of the stats package in R. A hierarchical cluster analysis was performed using the ward. D2 method in a cluster R package (**Maechler, 2019**).

RESULTS

Soil and poultry manure nutrient analysis

Table 1 Nutrient content of poultry manure, soil chemical characteristics and particles size distribution

Poultry manure		Soil	
Nutritional components		Chemical properties	
Total nitrogen (%)	3.5	Nitrogen (g/kg)	3.00
Total phosphorus (%)	3.45	Bray P (mg/kg)	16
Ca (%)	0.32	Exc Ca (cmol/kg)	7.56
Mg (%)	0.52	Exc Mg (cmol/kg)	0.22
K (%)	2.24	Exc Na (cmol/kg)	0.56
Mn (%)	0.02	CEC (cmol/kg)	10.03
Fe (%)	0.47	Exc k (cmol/kg)	0.56
Cu (%)	0.03	Mn (mg/kg)	76
Na (%)	0.23	Fe (mg/kg)	145
Zn (%)	0.03	Zn (mg/ kg)	17
pH in H ₂ O	8.30	Cu (mg/kg)	2
pH in KCl	8.10	pH in H ₂ O	6.85
Organic carbon (%)	18.1	pH in KCl	6.13
Organic matter (%)	31.2	Organic carbon (g/kg)	12.4
		Organic matter	2.1
		Sand (g/kg)	789
		Silt (g/kg)	91
		Clay (g/kg)	120
		Soil textural class	Sandy loam

Plant growth characteristics

For At 2 weeks, the mean values of the plant height of the control and the inoculated plants are relatively close (Table 2). Starting from 3 weeks, we start seeing clear disparities in the mean values up to the 5th week. At 2 weeks, combination of *Glomus mosseae* and 6.25 g poultry manure followed by sole application of poultry manure. At the 5th week, combination of *Glomus mosseae* and 6.25 g manure still have the highest value, the same as the combination of *Glomus deserticola* and 12.5 g manure which is 66.33 cm followed by single application of 6.25 g manure which is 61.67 cm. In relation to the control, at 2, 3, 4, and 5 weeks, the control mean value is higher than 4, 6, 1, and 0 numbers of treatments respectively.

Table 2 Effect of mycorrhizal and poultry manure application on plant height (cm) at 2,3,4 and 5 WAP

Treatments	2	3	4	5
Control	21.67 cd	28.50 bc	34.33 e	35.67e
G.d	21.00 cd	23.83 cd	38.67 de	55.00 cd
G.m	21.83 cd	26.50 bc	42.00 cd	56.67 cd

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2pm = 12.5 g poultry manure, WAP = Week After Planting

Table 2 Cont.

Treatments	2	3	4	5
G.c	20.73 d	24.67 cd	34.16 e	48.33 d
G.g	23.00bc	27.17 bc	41.67 cd	57.67 bc
1pm	26.67 a	32.67 a	50.33 a	61.67 ab
2pm	23.67 ab	28.83 bc	39.33 a	58.67bc
G.d + 1pm	21.00 cd	24.17 cd	36.67 a	47.00 d
G.m + 1pm	27.33 a	33.50 a	48.83 ab	66.33 a
G.c + 1pm	21.33 cd	25.83 cd	38.00 a	51.67 d
G.g + 1pm	24.17 ab	28.50 bc	45.50 bc	57.33bc
G.d + 2pm	24.00 ab	31.50 ab	50.00 a	66.33 a
G.m + 2pm	26.50 a	31.83 ab	45.00 bc	57.67bc
G.c + 2pm	22.00 bc	30.00 ab	41.83 cd	57.67bc
G.g + 2pm	26.83 a	30.67 ab	39.38 de	55.00 cd
F Statistics	0.48 ^{ns}	0.51 ^{ns}	0.52 ^{ns}	0.69 ^{ns}
C.V.	25.32	26.75	27.89	21.87

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2pm = 12.5 g poultry manure, WAP = Week After Planting

The number of branches increases at the different weeks (Table 3). At 2 weeks, treatments *Glomus mosseae* and combination of *Glomus clarum* with 12.5 g manure are statistically different while the control is not like any of the other treatment at 3 and 5 weeks, the values recorded are not statistically different for the number of leaves (Table 4) at 2 weeks, all treatments are significantly higher than the control, same for the period of the experiment. However, the combination treatments have significant values than the single treatments and the control. Statistically, the responses of the leaf area of the plants to the various inoculations at the different weeks are not different at each week (Table 5). However, the combined treatments gave higher leaf area than the other treatments.

Table 3 Effect of mycorrhizal and poultry manure application on number of branches at 2,3,4, and 5 WAP

Treatments	2	3	4	5
Control	1.67 b	3.00 a	3.33 c	5.66 a
G.d	2.00 ab	2.66 a	4.00 bc	6.33 a
G.m	2.33 a	3.33 a	4.33 abc	5.66 a
G.c	2.00 ab	2.66 a	4.00 bc	5.66 a
G.g	2.00 ab	2.66 a	4.33 abc	6.67 a
1pm	2.00 ab	3.67 a	5.00 ab	6.67 a
2pm	2.00 ab	3.00 a	4.67 abc	5.67 a
G.d + 1pm	2.00 ab	3.33 a	4.00 bc	6.33 a
G.m + 1pm	2.00 ab	3.33 a	5.00 ab	6.33 a
G.c + 1pm	1.67 ab	2.67 a	4.00 bc	6.33 a
G.g + 1pm	2.00 ab	3.67 a	4.67 abc	6.33 a
G.d + 2pm	2.00 ab	3.33 a	4.00 bc	7.00 a
G.m + 2pm	2.00 ab	3.33 a	5.00 ab	6.33 a
G.c + 2pm	2.33 a	2.67 a	4.66 abc	6.00 a
G.g + 2pm	2.00 ab	3.67 a	5.67 a	6.00 a
F statistics	1.07 ^{ns}	1.15 ^{ns}	1.67 ^{ns}	0.64 ^{ns}
C.V	14.91	20.33	17.49	14.43

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure, WAP = Week After Planting

Table 4 Effect of mycorrhizal and poultry manure application on number of leaves at 2, 3, 4, and 5 WAP

Treatments	2	3	4	5
Control	6.67 b	10.00 bc	15.33 bc	16.67 b
G.d	8.33 ab	10.33 bc	14.33 c	19.67 ab
G.m	9.00 ab	10.67 bc	15.33 bc	18.00 ab
G.c	8.33 ab	10.67 bc	14.00 c	21.33 ab
G.g	8.00 ab	11.00 ab	16.00 ab	26.00 a
1pm	9.00 ab	13.00 a	16.67 ab	23.33 ab
2pm	8.00 ab	11.00 ab	13.33c	18.33 ab
G.d + 1pm	8.67 ab	11.66 ab	13.00 c	18.33 ab

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure, WAP = Week After Planting

Table 4 Cont.

Treatments	2	3	4	5
G.m +1pm	8.00 ab	13.33 a	16.33 ab	18.00 ab
G.c +1pm	7.33 ab	11.33ab	14.67 c	22.00 ab
G.g +1pm	10.33 a	13.33 a	17.33 a	23.33 ab
G.d +2pm	9.00 ab	14.00 a	18.67 a	23.33 ab
G.m +2pm	8.33 ab	13.33 a	18.00 a	21.00 ab
G.c +2pm	8.67 ab	11.67 ab	16.67 ab	20.33 ab
G.g +2pm	8.33 ab	12.66 ab	16.67 ab	20.00 ab
F Statistics	0.77 ^{ns}	0.87 ^{ns}	1.06 ^{ns}	1.16 ^{ns}
C.V.	19.44	20.33	18.75	20.24

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure, WAP = Week After Planting

Table 5 Effect of mycorrhizal and poultry manure application on leaf area at 2, 3, 4, 5 WAP

Treatments	2	3	4	5
Control	11.32 a	20.57 a	21.27 c	25.53 b
G.d	12.63 a	13.77 a	22.30 bc	26.76 ab
G.m	12.00 a	19.63 a	23.80 abc	29.13 ab
G.c	11.43 a	17.60 a	21.23 c	26.83 ab
G.g	14.67 a	17.47 a	27.36 abc	33.56 ab
1pm	14.80 a	25.90 a	38.33 a	42.63 a
2pm	11.86 a	27.33 a	27.77 abc	33.63 ab
G.d + 1pm	11.86 a	27.33 a	23.47 abc	29.13 ab
G.m +1pm	17.26 a	20.87 a	28.67 abc	33.63 ab
G.c +1pm	12.03 a	15.07 a	27.77 abc	31.67 ab

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure, WAP = Week After Planting.

Table 5 Cont.

Treatments	2	3	4	5
G.g + 1pm	12.18 a	16.63 a	27.30 abc	33.10 ab
G.d + 2pm	15.07 a	22.67 a	35.00 abc	39.96 ab
G.m +2pm	19.97 a	21.97 a	37.57 ab	43.40 a
G.c + 2pm	13.60 a	22.97 a	30.63 ^{abc}	35.77 ab
G.g + 2pm	16.67 a	24.60 a	30.93 abc	37.77 ab
F Statistics	0.83 ^{ns}	0.92 ^{ns}	1.40 ^{ns}	1.30 ^{ns}
C.V.	33.95	34.35	28.62	25.48

Legend: Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure, WAP = Week After Planting.

Single treatments of *Glomus deserticola*, *Glomus gigaspora*, *Glomus mosseae*, and combination treatments of *Glomus mosseae*+6.25 g manure, *Glomus gigaspora*+6.25 g manure, *Glomus deserticola*+12.5 g manure, *Glomus mosseae*+12.5 g manure, *Glomus clarum*+12.5 g manure, and *Glomus gigaspora*+12.5 g manure are not statistically different from one another (Figure 1). However, single treatments of 6.25 g manure gave the highest fresh and dry biomass yields. Furthermore, treatments with *Glomus clarum* inoculum, gave the highest mycorrhizal count. The control and the *Glomus deserticola* treated plants are not statistically different in their mycorrhizal count. It was observed that combination treatment of *Glomus clarum*+6.25 g manure gave the highest root colonization percentage and all treatments with 12.5 g of manure were seen to show higher root colonization than those with 6.25 g or those without manure. This suggests that high manure content influences the root colonization ability of the mycorrhiza species. Furthermore, treatment *Glomus gigaspora*+6.25 g manure produced the highest number of seeds followed by *Glomus clarum*+12.5 g manure and *Glomus mosseae*+6.25 g manure. The grain yield is similar in all treatments except for the control which is much lower than the other treatments. Like the grain yield, days to 50% flowering is similar for all treatments in their effects.

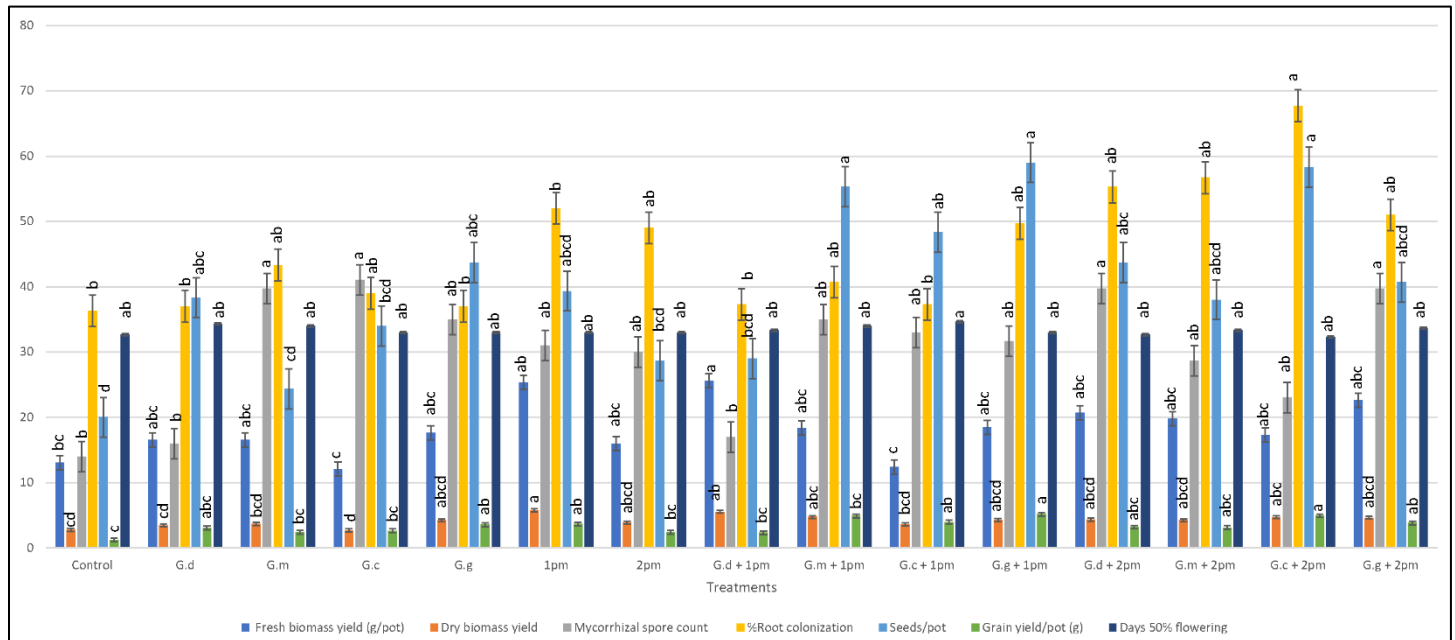


Figure 1 Effect of mycorrhizal and poultry manure application on biomass yield, grain yield, mycorrhiza spore count, root colonization, and days to 50% flowering. Means in the same column with the same letter are not significantly different at 5% level of probability using DMRT. G.d = *Glomus deserticola*, G.m = *Glomus mosseae*, G.c = *Glomus Clarum*, G.g = *Glomus gigaspora*, 1 pm= 6.25 g poultry manure, 2 pm = 12.5 g poultry manure.

Principal component analysis

The principal component of the variances taken by component responses of the plants on the traits over the treatments used in the study are represented in a biplot (Figure 2). PC1 and PC2 account for 67.9% of the total variances observed. Among the variables, the plant height, number of branches, leaf area, and dry biomass yield are the major contributing components of PC1 while number of seeds, fresh biomass yield, and grain yield contribute highest to PC2

(Table 6). Treatments that improve fresh biomass yield and number of seeds also increases the grain yield.

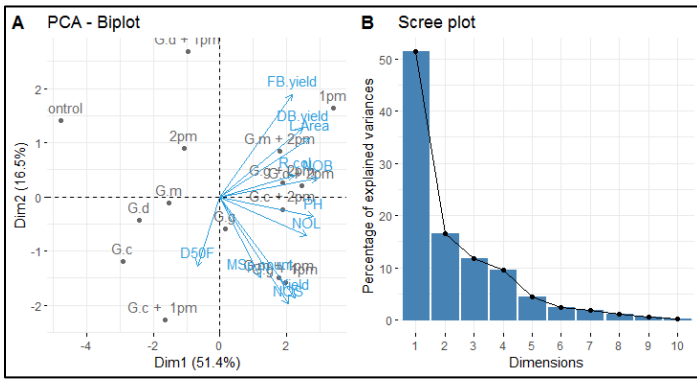


Figure 2 Biplot representation of the PCA analysis. (A.) PC 1 and PC 2 biplot using quantitative trait scores (B.) Scree plot of the loadings explaining the variances at each PC

Table 6 Trait contributions, eigenvalues, and cumulative percentage of the first five components

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
PH	13.707967	0.6997785	0.2128521	3.6608263	5.4231327
NOB	15.099067	0.6241507	5.0838851	1.3247173	0.0085977
NOL	11.749025	2.7852839	2.7084376	1.3353652	23.230957
L.Area	12.434389	6.3353539	0.4489379	3.9602473	12.312132
FB.yield	8.1813151	19.462155	9.2958483	0.360694	7.7038025
DB.yield	10.618197	8.6955659	8.4509858	5.7459467	1.9552202
MSp.count	2.5356375	11.942743	0.0019746	52.073125	3.2838357
R.col	8.7506308	0.8676604	21.793444	0.3613102	28.22655
NOS	7.3013965	21.120961	0.4069789	17.496557	0.4241143
D50F	0.7951592	8.803347	51.394001	0.4938005	17.420647
Yield	8.8272156	18.663	0.2026554	13.187411	0.0110105
eigenvalue	5.6580151	1.8121661	1.2975681	1.0577207	0.4843258
Percentage variance	51.436501	16.474238	11.796074	9.6156427	4.4029622
Cumulative percentage variance	51.436501	67.910738	79.706812	89.322455	93.725417

Cluster analysis

The treatments were clustered into 4 based on their effects on the plant responses (Figure 3). Each group of clusters is distinct from the others by their color. Higher number of the combination treatments are represented close to each other while the same is observed for single treatments.

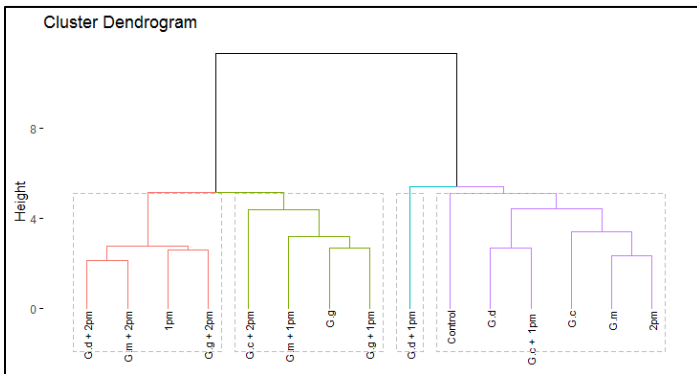


Figure 3 Hierarchical clustering dendrogram analysis; Euclidean distance was used and the associations between groups were done by the Ward method for the treatments with respect to the plant responses

Correlation analysis

There are lots of significant correlations among the traits scored (Figure 4).

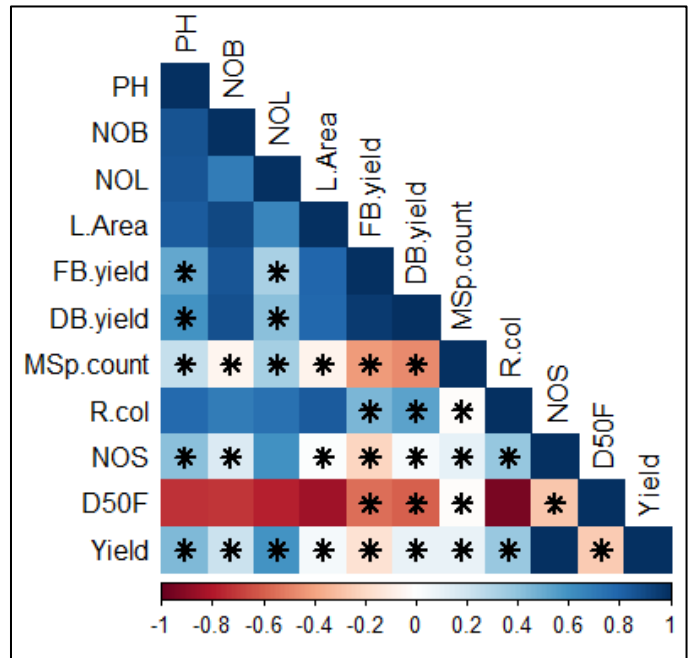


Figure 4 Correlations among the traits scored; Pearson's rank correlation matrix and performance analytic chart of the variables showing the relationship among the variables scored on the plants. (Blue color indicates a highly positive correlation and red color indicates a highly negative correlation among the different traits. PH: plant height(cm), NOB: number of branches, NOL: number of leaves, L.Area: leaf area, FB.yield: fresh biomass yield (g/plant), DB.yield: dry biomass yield (g/plant), MSp.count: mycorrhiza count, R.col: percentage root colonization, NOS: number of seeds, D50F: days to 50% flowering, Yield (g/plant)), *= significant, $p < 0.05$.

The level of significance of the correlations at $p < 0.05$ is shown by the asterisks. Either positive or negative correlations, the asterisks indicate if it is statistically significant or not. The red colors show negative correlations while the blue colors show positive correlations. The deeper the colors, the stronger the correlations. Plant height has a positive correlation with all other traits except days to 50% flowering but only correlations with fresh and dry biomass yield, mycorrhiza spore count, number of seeds, and yield that are significant statistically. Number of branches on the other hand has a positive correlation with number of leaves, leaf area, fresh and dry biomass yield, root colonization, number of seeds, and yield with the last two being only the positive significant correlations. Number of leaves is positively and significantly correlated with fresh and dry biomass yield, mycorrhiza spore count, and yield while leaf area is significantly positively correlated with yield. Fresh biomass yield is significantly positively correlated with percentage root colonization but significantly negatively correlated with mycorrhiza spore count, number of seeds, days to 50% flowering, and yield. Dry biomass yield correlates positively and significantly with percentage root colonization and yield but negatively and significantly with mycorrhiza spore count and days to 50% flowering while mycorrhiza spore count and root colonization both correlate positively and significantly with number of seeds and yield but negatively with days to 50% flowering. Furthermore, number of seeds correlates positively with yield while days to 50% flowering has negative correlations with all the traits.

DISCUSSION

Crop yield is affected by nutrient availability, pests and diseases, water availability, and poor soil condition among others (Donatelli et al., 2017; Rööß et al., 2018; J. Zhang et al., 2020). AMF enhances plant ability to absorb minerals and improve growth through mineral solubilization, production of growth hormones, etc. Manure from various sources have been identified in plant growth promotion (Abbas et al., 2020; Ekinci et al., 2019) with the sources playing a crucial role (Bibiano et al., 2019).

Principal component analysis

Biplot represents the association among different traits, and the length of the lines shows the contribution of each trait in the variations observed (Figure 2). The eigenvalues and the corresponding factors are sorted by descending order of how much of the initial variability they represent. The Eigenvalue significance

criterion, as described by Kaiser (1960) was used to select statistically significant principal components. The biplot analysis can be used to select the best treatment in breeding for a trait.

Clustering and Correlation analysis

The clustering grouped majority of the combined treatments together in the same clusters (Figure 3), hence we can say that they produce similar responses different from the sole treatments. The correlation matrix shows traits that have impact on each other (Figure 3). It aids the selection of traits without over-picking traits for improved breeding. From the traits, tall plants produce high yield hence, farmers will prefer treatments that favor tall plants (Figure 2) so they can have high yield.

CONCLUSION

The study concludes that the treatments have effects on the growth and yield parameters of soybean. It was also observed that combination treatments of AMF with higher quantity of manure produced the best result on growth and yield.

This study was conducted in a screenhouse however due to diverse environmental factors, diversity in soil microbiome of the field, it is suggested that further the study should be replicated on the field to know if these treatments will still yield the same result.

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