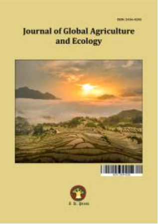

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Effect of Arbuscular Mycorrhizal Fungi on the Growth and Yield of Soybean (*Glycine max* L. Merrill) in Bauchi, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author MI designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AA and AGE managed the analyses of the study. Author AJN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soybeans (*Glycine max* L.) globally has been regarded as an economically important commodity that is highly traded and also a vital legume used as food source for both humans and animals. The objective of the study therefore is to determine the effect of Arbuscular mycorrhizal fungi (AMF) (*Glomus intraradices*) on the growth and yield of soybean (*Glycine max* L.). The experiment was conducted in a screen house where two varieties of soybeans (TGX 1448 and TGX 1951) were

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grown in 1 litre pods, filled with sterilized soil and three seeds were sown into each pod at a depth of 2 cm until germination, then reduced to one seedling. Different AMF dose (10 g, 20 g, 30 g, and 40 g) was inoculated at the time of seed sowing and non-inoculated pods as control (0 g). Various parameters were taken into consideration like plant height and number of leaves while shoot dry biomass, root dry biomass and yield attributes were taken at harvest. It was observed that the inoculated plants performed higher than the non-inoculated plants. Growth parameters such as plant height, number of leaves, shoot dry biomass, root dry biomass, and yield attributes increased with increase AMF dose. Therefore, it is concluded that AMF inoculation increase growth and yield of soybeans and can serve as biofertilizer.

Keywords: Glycine max L.; Arbuscular mycorrhizal fungi; inoculated; biofertilizer; glomus intraradices.

ABBREVIATIONS

AMF	*: Arbuscular Mycorrhizal Fungi*
BASADP	*: Bauchi State Agricultural Development Programme*
CRD	*: Completely Randomized Design*
DSAAT	*: Digital Situational Awareness Assessment and Training*
SOM	*: Soil Organic Matter*

1. INTRODUCTION

Soybeans (*Glycine max* L.) over the years have been regarded as one of the most economically important legumes in the food chain, with more than one fourth of the global population depending on it for food and other essentials such as animal feeds [1,2]. The importance of soybean (*Glycine max* L.) as both oil crop and legumes to the food chain is paramount, belonging to the family Fabaceae [3,4]. Soybeans has 20% oil, when dry with other vital amount of minerals and vitamins present, and also, provides high quality protein for many households and processing industries in Nigeria [5,6,7].

Legumes have been an important way of earning for many farmers in most underdeveloped and developing nation, soybeans being known to improve soil fertility due to the ability to fix atmospheric nitrogen into the soil in the form that can be utilized by plants, thereby, lessening the need for organic and mineral fertilizers [8]. In contrast, more than half of total nitrogen been added to the soil emanate from legumes – rhizobia symbiosis relationship [9]. Low yield in soybean farming are usually associated with nutrients imbalance, nutrients leaching and also, due to limited nutrients in the non-fertile soil [9,10,11].

Arbuscular Mycorrhiza fungi (AMF) form symbiosis relationship with most plant species by colonization of the host plant roots in order to source carbohydrates for their growth, development and continuous survival while in return, it provides minerals, nutrients and water to the host plant [2,12,13,14]. A study by [15] reveals that myristate can be a source of carbon and energy for AMF. Immediately the spore germinate, colonization of the plant root start by forming a hyphopodium on the surface of the root, which penetrate the rhizodermis through a pre-penetration apparatus, these colonizes root tissue intercellularly form hyphae from which highly branched structure arbuscules developed in cortical cells which the fungi use to release minerals to the host plant [12,16,17,18]. Glomalin secreted by AMF help improves soil organic matter (SOM), soil structure, microbial activity, mitigate drought effects [19,20,21], bioremediation, and reduce loss of fertility [22,23,24,25,26].

The influence of AMF towards reduction of oxidative processes and reducing soil organic matter have led to reduction of the amount of soil based carbon-dioxide (CO_2) emission resulting from organic carbon stock in the soil [27,28].

Several scholars have reported positive effects of using AMF to boost growth and yield of plants particularly legumes and cereals [3,29,30,31,32,33,34,35] and similarly, other scholars have reported no or less effects of using AMF [36,37]. Therefore, it is necessary to investigate the effect of different dose of AMF on the growth and yield of soybeans (*Glycine max* L.) varieties (TGX 1448 and TGX 1951).

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted in the Screen house of Abubakar Tafawa Balewa University in Bauchi, Bauchi State, Nigeria.

2.2 Soil Analysis

pH (H_2O), Electrical Conductivity (dsm^{-1}), Exchangeable Acidity (cmol kg^{-1}), Ca^{2+} (cmol kg^{-1}), Mg^{2+} (cmol kg^{-1}), K^+ (cmol kg^{-1}), Na^+ (cmol kg^{-1}), Cation Exchange Capacity (cmol kg^{-1}), Total Exchangeable Base (cmol kg^{-1}), Base Saturation (%), N (%), Organic Carbon (%), Organic Matter (%), Carbon to Nitrogen, Available Phosphorus (mg kg^{-1}), Clay, Sand, Silt, Texture were determined.

2.3 Source of Soybean Seeds

Two varieties of soybean (TGX 1448 and TGX 1951) were purchased from Bauchi State Agricultural Development Programme (BASADP), Bauchi, Nigeria. Viability test was carried out according to [38]

2.4 Source of AMF Inoculum

AMF inoculum was sourced from University of Aberdeen, School of Biological Sciences, Aberdeen, Scotland.

2.5 Screen House Experiment

Plants were grown in 1 litre pot with 4 replications. Different concentations of AMF *Glomus intraradices* (10g, 20g, 30g, and 40g) were inoculated and non-inoculated pot was used as control. Growth characteristics such as (plant height, number of leaves, root and shoot biomass, yield) were determined.

The pre-planting soil was collected in a transparent Ziplock polythene bag and taken to University of Maiduguri, Department of Soil Science for physical and chemical analysis. The result of the pre-planting soil analysis is presented in Table 1.

2.6 Experimental Design and Treatment

The experiment was set-up in a completely randomized design (CRD) using 1 litre pots filled with 5 mm sieved soil. Three soybean seeds were planted into each pot at a depth of 2 cm which after germination others were removed, maintaining one at each pot. The inoculation of AMF (10g, 20g, 30g, and 40g i.e. average of 40 spores per 10 g) were done at the time of sowing.

2.7 Data Collection

Plant height, and number of leaves were recorded at two weeks intervals while root biomass, shoot biomass, weight of seeds and number of seeds per plant were recorded after harvesting i.e. at thirteen weeks.

2.8 Statistical Analysis

Data collected from growth indices (plant height, number of leaves, root biomass, shoot biomass and yield) were analysed using DSAAT statistical software on Microsoft excel and GraphPad Prism version 8.0 software.

3. RESULTS

The results of the physical and chemical properties of the experimental soil are presented in Table 1. The result indicated that soil pH was 6.68 with EC of 0.84 (dsm^{-1}). Available phosphorus value of 12.25 (mg kg^{-1}) and the texture was identified as sandy loam.

Fig. 1A shows the plant height of *Glycine max* variety TGX 1448 inoculated with different dose of arbuscular mycorrhiza fungi (AMF) of which at harvest, there is no significant difference between 30g and 40g AMF while 0 g i.e. control recorded less plant height and there is significant difference between control (0g), 10g and 20g AMF. Fig. 1B shows plant height of *Glycine max* variety TGX 1951 inoculated with different dose of arbuscular mycorrhiza fungi (AMF), at harvest, 30 g AMF has the highest plant height but there is no significant difference between 20 g, 30 g and 40 g while there is significant difference between control (0g), 10g and 20g AMF.

Fig. 2A shows number of leaves of *Glycine max* variety TGX 1448 inoculated with different dose of arbuscular mycorrhizal fungi (AMF), at harvest, 30g has the highest leaves number, but there is no significant difference between 30 g and 40 g AMF while there is no significant difference between control (0g), 10g and 20g respectively. Fig. 2B shows number of leaves of *Glycine max* variety TGX 1951 inoculated with different dose of arbuscular mycorrhiza fungi (AMF) at harvest, there is no significant difference between 20 g, 30 g and 40 g while there is significant difference between control (0g), and 10g.

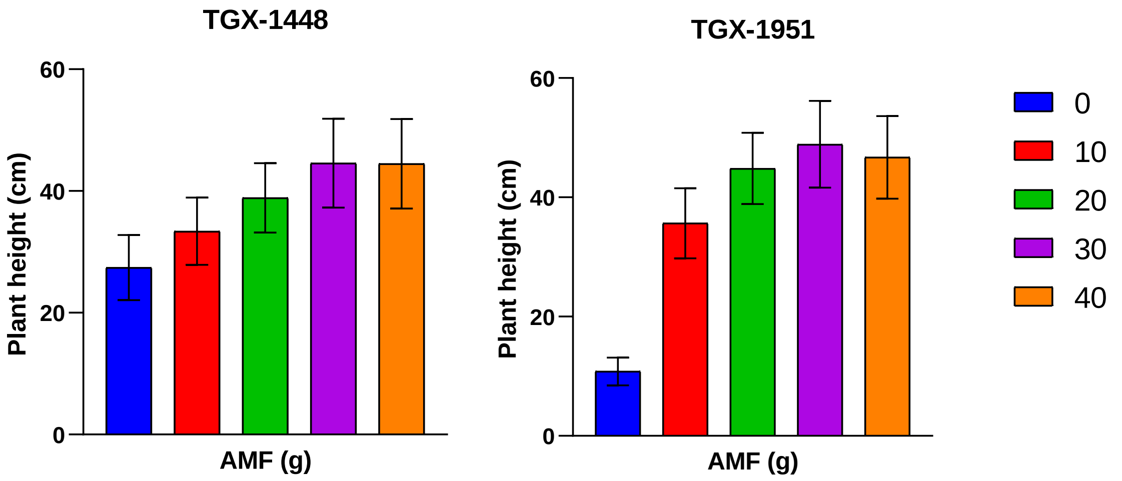
Table 1. Physical and chemical properties of the pre-planting soil

Soil property	Value
pH (H_2O)	6.68
EC (dsm^{-1})	0.84
EA (cmol kg^{-1})	1.90
Ca^{2+} (cmol kg^{-1})	2.40
Mg^{2+} (cmol kg^{-1})	3.60
K^+ (cmol kg^{-1})	0.17
Na^+ (cmol kg^{-1})	0.13
CEC (cmol kg^{-1})	6.30
TEB (cmol kg^{-1})	8.20
Base Sat. (%)	76.83
N (%)	0.18
OC (%)	0.64
OM (%)	1.10
C:N	3.56
AP (mg kg^{-1})	12.25
Clay	16.50
Sand	75.30
Silt	8.20
Texture	Sandy loam

EC-Electrical conductivity, EA-Exchangeable acidity, Ca^{2+} -Calcium, Mg^{2+} -Magnesium, K^+ -Potassium, Na^+ -Sodium, CEC- Cation exchange capacity, TEB- Total exchangeable base, Base sat- Base saturation, N-Nitrogen, OC- Organic carbon, OM- Organic matter,C:N- Carbon to Nitrogen, and AP- Available Phosphorus.

Fig. 3A shows shoot biomass of *Glycine max* (TGX 1448) inoculated with different dose of AMF 30g has the highest weight, followed by 40g. For shoot, there is no significant difference between control (0 g), 10 g, 20 g and 40 g AMF.

Fig. 3B shows shoot biomass of *Glycine max* (TGX 1951) inoculated with different dose of mycorrhizal (AMF). The weight increase with increased in AMF dose of which 40g has the highest weight in shoot biomass.



(A) **(B)**

Fig. 1. A - Effect of AMF (*Glomus intraradices)* on plant height of *Glycine max* (TGX 1448) B - Effect of AMF (*Glomus intraradices)* on plant height of *Glycine max* (TGX 1951)

(A) **(B)**

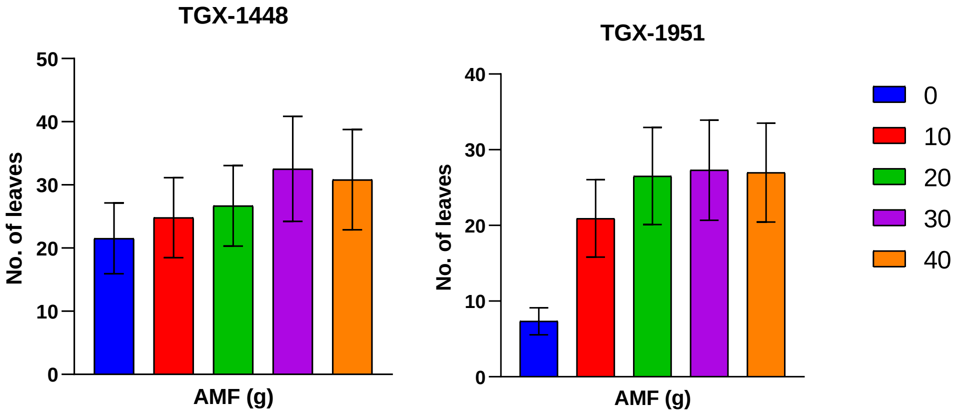


Fig. 2. A - Effect of AMF (*Glomus intraradices)* on number of leaves of *Glycine max* (TGX 1448) B - Effect of AMF (*Glomus intraradices)* on number of leaves of *Glycine max* (TGX 1951)

(A) **(B)**

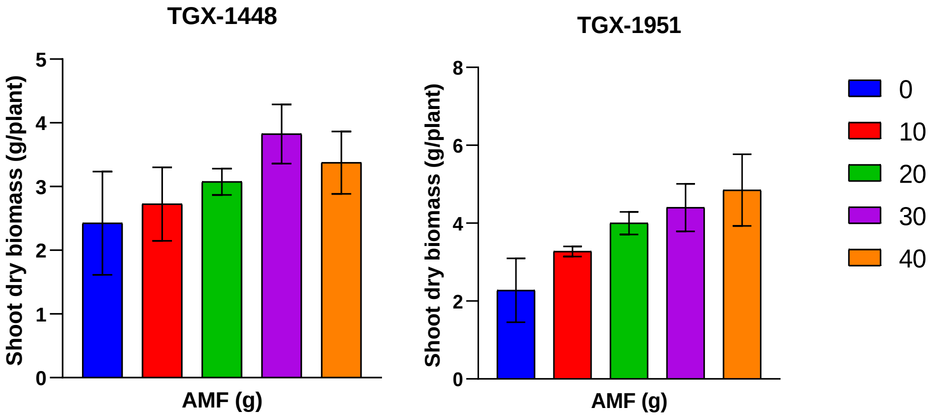


Fig. 3. A- Effect of AMF (*Glomus intraradices)* on shoot dry biomass of *Glycine max* (TGX 1448) B - Effect of AMF (*Glomus intraradices)* on shoot dry biomass of *Glycine max* (TGX 1951)

(A) **(B)**

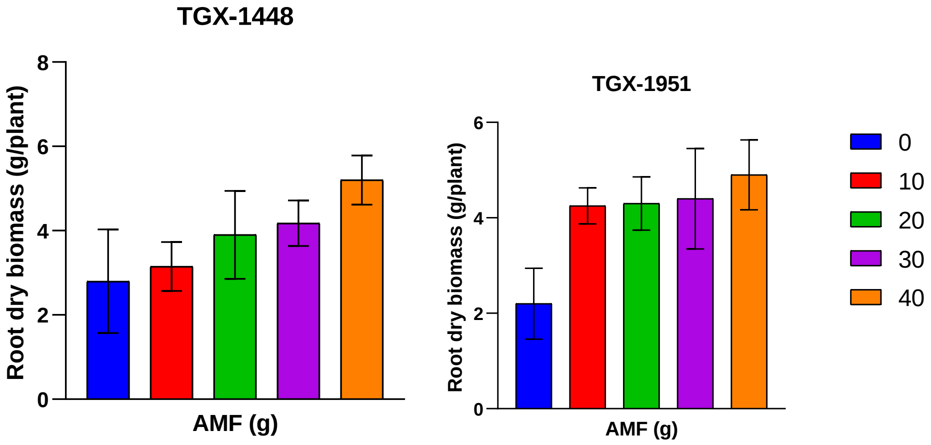


Fig. 4. A- Effect of AMF (*Glomus intraradices)* on root dry biomass of *Glycine max* (TGX 1448) B - Effect of AMF (*Glomus intraradices)* on root dry biomass of *Glycine max* (TGX 1951)

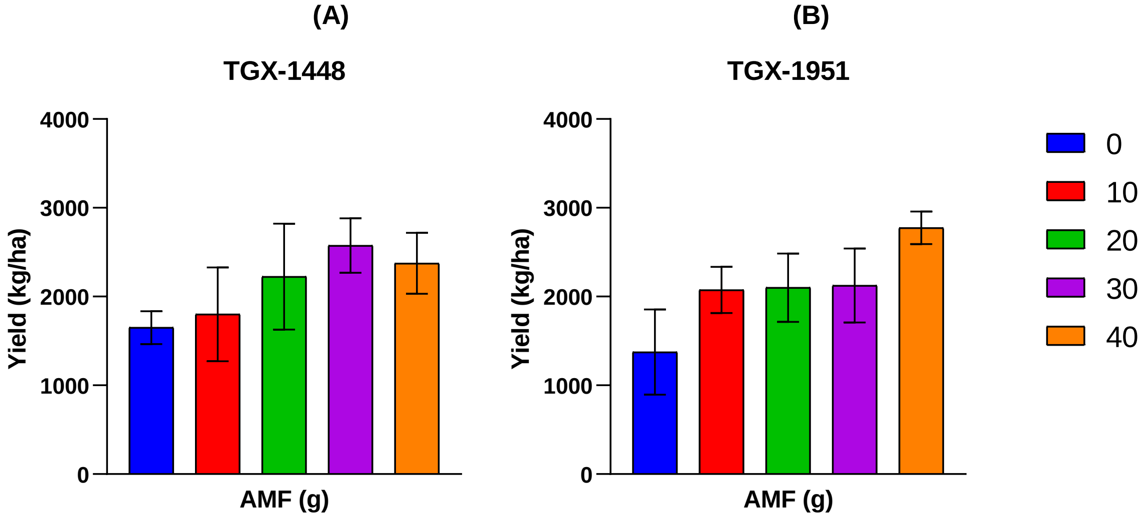


Fig. 5. A- Effect of AMF (*Glomus intraradices)* on root dry biomass of *Glycine max* (TGX 1448) B - Effect of AMF (*Glomus intraradices)* on root dry biomass of *Glycine max* (TGX 1951)

Fig. 4A shows root biomass of *Glycine max* (TGX 1448) inoculated with different dose of mycorrhizal (AMF). the weight increase with increased in AMF dose of which 40g has the highest root weight, while there is no significant difference between control, and 10g AMF. Subsequently, there is no significant difference between 20g, and 30g AMF. Fig. 4B shows root biomass of *Glycine max* (TGX 1951) inoculated with different dose of mycorrhizal (AMF). In root biomass, the weight increase with increased in AMF dose of which 40g has the highest weight in root biomass while there is no significant differences between control, and 10g, 20 g and 30 g AMF. Subsequently, there is significant difference between non- mycorrhizal inoculated control (0g) with the inoculated mycorrhizal ones.

Fig. 5A shows yield of different varieties of *Glycine max* (TGX 1448) inoculated with different dose of AMF. Among the different treatments of variety TGX 1448, 30 g has best yield as compared to the other treatments and there is no significant difference between control, and 20 g, 30 g and 40 g AMF. Fig. 5B shows yield of variety of *Glycine max* (TGX 1951) inoculated with different dose of AMF. Variety 2-TGX 1951 40 g has the best yield as compared to the different treatments and there is no significant difference between 10 g, 20 g, and 30 g AMF. Subsequently, there is significant difference between non- mycorrhizal inoculated control (0g) with the inoculated mycorrhizal ones.

4. DISCUSSION

The used of AMF (*Glomus intraradices*) have increased plant growth and yield attributes of the two varieties (TGX 1448 and TGX 1951) of soybeans. These increase in overall growth and yield have earlier been reported by [3,39]. The presence of AMF has influence growth and yield attributes such as plant height and number of leaves due to the fact AMF may have influence nutrient uptake. AMF increases colonization in the rhizobia which subsequently provides the support by enhancing photosynthetic rate through the supply of phosphorus and nitrogen. The photosynthetic enzymes responsible for light harvesting complex solely depends on essential nutrients supply by AMF of which phosphorus are known to stimulate many functions in plants such as canopy photosynthesis, nutrient movement and energy transfer in plants [40,41,42,43]. Similarly, AMF has positive effect on antioxidant enzyme activities in plants [44].

The symbiotic relationship between plant and mycorrhiza positively enhances the root length , root biomass, root density, increases nutrient uptake especially nitrogen, phosphorus, iron and zinc [45,46,47,48] and also, uptake of potassium [49,50]. Root colonization of the both varieties of soybeans (TGX 1448 and TGX 1951) inoculated with AMF were higher which may have resulted due to optimal value of available phosphorus in the soils [51,52]. AMF symbiosis is more established predominantly in marginal soil allowing the secretion of root exudates by the plant which increased colonization in the rhizobia [3,53,54].

Bacterial growth and vitality are influenced by mycelial exudates which enhance the community of bacteria in the rhizosphere [55,56,57]. The ability of AMF hyphae to form symbiotic association with the plant root depends on the different bacterial groups present in the soil [58,59]. According to [60] and [61] AMF can be used as effective tool for ameliorating the negative impact of drought stress on plant by enhancing plant resistance and tolerance to abiotic stress which resulted in increased yield.

The plant height and number of leaves between the inoculated AMF plants and the non-inoculated AMF plants (0 g) in both soyabean varieties is visible, the inoculated plants performed higher than the non-inoculated AMF plants which agrees to the study of [62]. Furthermore, shoot dry biomass and root dry biomass in the inoculated AMF plants exhibit similar pattern of performance with plant height and number of leaves of which the inoculated AMF plants have higher weight than the non-inoculated AMF plants which agrees with the study of [62].

In contrast, high yield performance recorded in TGX 1951 at high AMF dose plants relates to increase growth parameters specifically plant height and number of leaves, of which high photosynthesis directly relates to increased assimilatory surface, resulting in increased shoot and root biomass and finally, increased yield attributes [3,63].

5. CONCLUSION

In conclusion, AMF (*Glomus intraradices*) exhibits greater potential to increased yield under favourable condition. The result validates the influence of AMF on the growth and yield of soybeans varieties (TGX 1448 and TGX 1951). It reveals that high yield attributes were observed with increased AMF dose in both varieties of soybeans which relates to high AMF colonization around the roots, thereby increasing both water and nutrient uptake through the roots by the plant. TGX 1951 has the best performance with AMF inoculation then TGX 1448.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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