Original Research Article

Evaluation of the effect of *Glomus mosseae* inoculation on agronomic parameters of maize (*Zea mays L.*) under a substrate subjected to gold mining

ABSTRACT

Aim: evaluate, in a greenhouse, the effect of the AMF, *Glomus mosseae*, on the agronomic performance of maize grown on soil degraded by gold mining.
Study design: for restoring soil quality, the effect of using Arbuscular Mycorrhizal Fungi (AMF) as a fertilizer was tested on samples of washed gold-bearing soils in comparison with soils taken under natural vegetation on maize in greenhouse conditions.
Place and Duration of Study: University of Lomé, between September 2022 and January 2023.
Methodology: A Completely Randomized Design (CRD) with six replicates was adopted. Four treatments namely pure mineral fertilizers (To), pure AMF (*Glomus mosseae*) (T1), the combination of AMF and mineral fertilizers (T2) and a control (Co) were tested. A pot of 5 liters capacity having received 5 kg of soil substrat composed the experimental unit.
Results: gold-bearing soils are sandy and poor in organic and mineral compounds compared to soils under natural vegetation. The mycorrhization parameters do not take soil type into account. On average, 73.62 % of plants in simple inoculation were mycorrhized where as 33.43 % of plants were mycorrhized in inoculation with a synthetic fertilizer (NPK+Urea) at 60 days after sowing. The respective mycorrhization intensities corresponding to these mycorrhization rates are 41.43 and 45.67 % for the same period. The inoculation with AMF affect positively the growth, development and the productivity of maize compared to the control.
Conclusion: Results suggest that *G. mosseae* can be used as a biofertilizer on gold mining soils in Togo for sustainable maize production.

Keywords: Gold mining, Degraded soil, Arbuscular Mycorrhizal Fungi, Maize, Togo.

1. INTRODUCTION

Gold mining is an activity that generates income for rural populations, but also causes many environmental problems. This activity leads to deforestation, soil degradation, soil and water pollution, loss of biodiversity and the shaping of the landscape [1–4]. Gold mining is generally accompanied by the destruction of vegetation cover, the opening of trenches and shafts, significant excavation of the sandy-clay layer and the overturning of soils, leading to the gradual destruction of arable land. This degradation of the plant cover leads to severe erosion and, ultimately, irreversible soil sterilization due to the disappearance of the humus-bearing horizon [5,6].

In Togo, artisanal gold mining is not without environmental consequences. In the Central Region of Togo, gold mining leads to the degradation of natural resources and has environmental consequences on the landscape [4]. Gold-mining sites are not restored, and the proliferation of these sites leads to the reduction of land suitable for agriculture and impacts the food and nutritional security of populations [5]. In line with the challenges of sustainable development, there is an urgent need not only to preserve soils, but also to restore the fertility of land destroyed by gold mining.

Studies have shown the advantage that arbuscular mycorrhizal fungi (AMF) provide to plants by making accessible mineral elements that are difficult to access naturally [7,8]. Plant-fungus symbioses are extremely widespread, affecting 80 to 90% of plant species [9]. Mycorrhizae are very important in the restoration of degraded natural resources [10]. These mycorrhizae are also known for their ability to give plants a better capacity to acquire water, maintain soil fertility and increase crop yields in tropical environments [7,11,12]. AMF are beneficial soil microorganisms that establish mutualistic associations with a host of food crops [13] including maize (*Zea mays L*.), by improving soil characteristics and promoting plant growth and resistance or tolerance to biotic and abiotic stresses [14,15].

In terms of scientific knowledge, very little work has been carried out in Togo on the use of AMF associated with maize cultivation on degraded soil. The present study is a contribution to the management of soils degraded by gold mining. It aims to evaluate, in a greenhouse, the effect of the AMF, *Glomus mosseae*, on the agronomic performance of maize grown on soil degraded by gold mining.

2. MATERIAL AND METHODS

2.1 Experimental frame

The trial was conducted under glass at the Agronomic Experiment Station of the University of Lomé (latitude 6°10'25,52''N and longitude 1°12'37,09''E) (Fig. 1). The station enjoys an equatorial Guinean climate. Annual rainfall varies from 800 to 1100 mm [16]. Greenhouse trial conditions were a photoperiod averaging 12 hours, an average temperature ranging from 24°C in the morning to 35°C mid-day and 24°C in the evening.

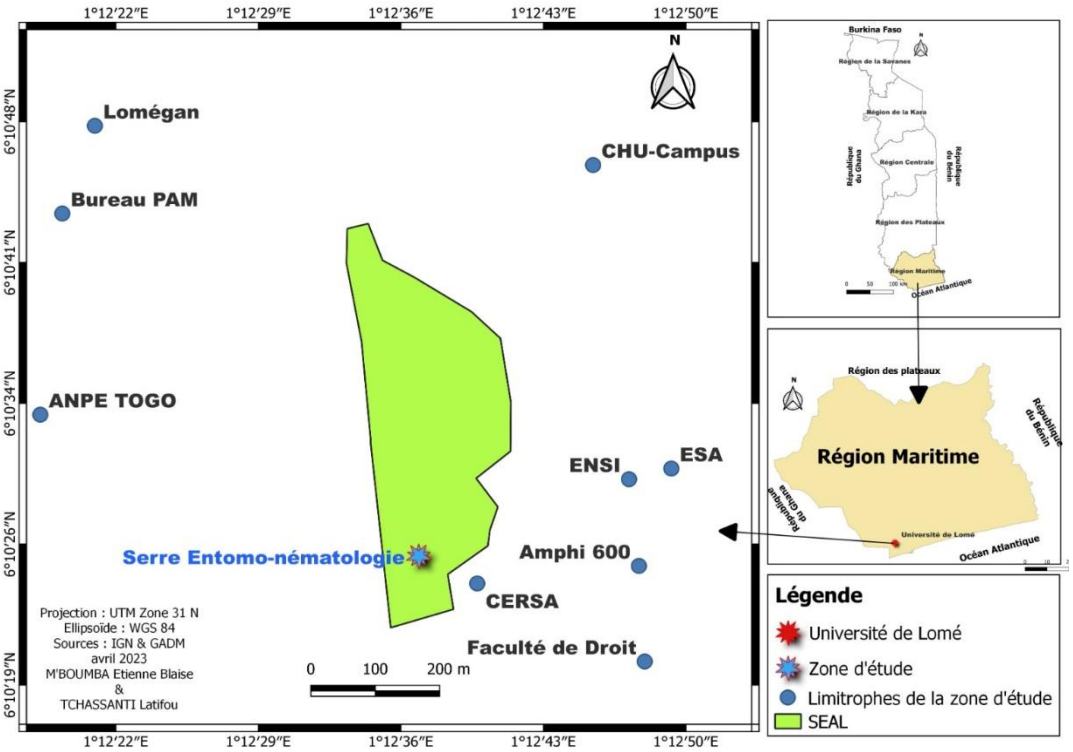

Fig. 1. Site location

2.2 Plant material

The study focused on a maize variety, TZEE W Pop STR QPM (TZE), whose seeds are white semihorned. It is an extra-early maize variety with a vegetative cycle of 80 to 85 days and a potential yield of 3.5 t ha^{-1} [17].

2.3 Fungal material

The AMF isolate, *G. mosseae* obtained from Mushroom Biotechnology Laboratory (LBC) of the Department of Plant Biology at Cheikh Anta DIOP University in Senegal was used in this experiment

2.4 Types of growing media

The soils used for this experiment were collected from the locality of Kéméni, Prefecture of Tchaoudjo, Togo. Two types of substrate were used for the trial: a soil collected under natural vegetation (SSVN) as a control (latitude 9°13'57.91''N and longitude 1°15'14.10''E) and a washed gold soil (SAL), the soil resulting from the washing of mineralized soils for alluvial gold recovery (latitude 9°12'24.86''N and longitude 1°14'34.82''E). These soils were analyzed at the Soil-Water-Vegetation-Fertilizers laboratory of the Togolese Institute of Agricultural Research (ITRA) in Lomé. The analyses focused on the 5-fraction particle size, organic matter rate (OM), organic carbon rate (C), total nitrogen content (N), assimilable phosphorus (P) content, the adsorbent complex: calcium (Ca), potassium (K), sodium (N), the Electrical conductivity (EC) and pH.

2.5 Experimental design

The experimental unit consisted of a plastic pot containing 5 kg of either soil collected under natural vegetation (SSVN) or washed gold soil (SAL). The trial consisted of a totally randomized set-up of 24 pots, with four treatments in six (6) replicates for each soil type. The treatments consisted of: uninoculated seeds and unfertilized pots; seeds uninoculated with *G. mosseae* but fertilized pots; seeds inoculated with *Glomus mosseae* and unfertilized plants; and seeds inoculated with *G. mosseae* and fertilized pots. Seeds were sown in each pot at a depth of 3 cm, with two seeds per pot. The pots were arranged so that the planting density has respected the cultural pattern of 80 cm × 40 cm between plants. Manual weeding was carried out to maintain one vigorous plant per pot after emergence. The fertilizers NPK 15-15-15 and Urea 46% N were applied at 15th and 45th days after sowing (DAS) respectively, at the recommended rates of 200 kg/ha and 100 kg/ha respectively. Throughout the crop cycle, the plants were watered regularly at the required field capacity of 500 cm^3 per poquet.

2.6 Data collection

Weekly observations were made on each pot from 10th DAS until the appearance of flowers to determine the germination rate, plant collar diameter, plant height, number of leaves per plant, leaf length and width per plant. Productivity parameters such as number of cobs per plant, height at panicle insertion, cob insertion height, cob length, cob diameter, dry above-ground biomass, dry cob weight, number of dry grains per cob, dry grain weight and cob weight were evaluated at harvest time. Above-ground and root biomass were cut and dried in an oven at 60°C until a constant weight was obtained. Dry weights were then determined using a precision balance (Techfit TF-1003, precision d = 0.1g). Germination rate was determined using the formula:

$$\mathrm{TG}\ (\%) = \frac{\text{number of seeds germinated}}{\text{number of seeds sown}} \mathrm{x}\ 100$$ where TG is the germination rate

2.7 Evaluation of mycorrhization parameters

Fine maize roots, previously placed in a 10 % KOH solution, were stained in Trypan Blue (0.05 %). These stained roots were cut into 1 cm fragments and mounted between slides. Mycorrhization frequency and intensity were assessed under a light microscope (x40 magnification), using the rating scale of Trouvelot et al. [18].

The mycorrhization frequency (F), reflecting the extent of infection of the root system, was measured using the formula:

$$\mathrm{F}\ (\%) = (\text{number of mycorrhizal fragments}/\text{total number of fragments})\ \mathrm{x}\ 100$$

Colonization intensity (M), which expresses the portion of the cortex colonized in relation to the entire root system, was measured using the formula:

$$\mathrm{M}\ (\%) = \frac{95\mathrm{n5} + 70\mathrm{n4} + 30\mathrm{n3} + 5\mathrm{n2} + \mathrm{n1}}{\text{total number of fragments}}$$

where n5 = number of fragments rated 5; n4 = number of fragments rated 4; n3 = number of fragments rated 3; n2 = number of fragments rated 2 and n1 = number of fragments rated 1.

Shrub intensity (a) was calculated using the formula:

$$\mathrm{a}(\%) = \frac{100\mathrm{mA3} + 50\mathrm{mA2} + 10\mathrm{mA1}}{100}$$

where mA3, mA2, mA1 are the percentages of m respectively assigned notes A3, A2, A1. With

$$\mathrm{mA3} = \frac{95\mathrm{n5A3} + 70\mathrm{n4A3} + 30\mathrm{n3A3} + 5\mathrm{n2A3} + \mathrm{n1A3}}{\text{number of mycorrhizal fragments} \times \mathrm{m}} \times 100$$

$$\mathrm{mA2} = \frac{95\mathrm{n5A2} + 70\mathrm{n4A2} + 30\mathrm{n3A2} + 5\mathrm{n2A2} + \mathrm{n1A2}}{\text{number of mycorrhizal fragments} \times \mathrm{m}} \times 100$$

$$mA1 = \frac{95n5A1 + 70n4A1 + 30n3A1 + 5n2A1 + n1A1}{\text{number of mycorrhizal fragments} \times m} \times 100$$

2.8 Statistical Analysis

The data collected were analyzed using R software version 4.1.3. Data in percentages of shrub quality, mycorrhization frequency and mycorrhization intensity were transformed using a circular function arcsin√((X 100^{-1})) prior to analysis, to reduce excessive discrepancies. The data were then subjected to an analysis of variance according to the experimental design adopted for this study. The different arithmetic means of the different treatments were compared using the PPDS test at the 5% threshold when a significant difference was found. The texture triangle of the United States Department of Agriculture [19] was used for soil textural classification, with the three sides of the triangle corresponding respectively to the percentages of sand, silt and clay.

3. RESULTS

3.1 Soil physico-chemical characteristics

Analytical results for the soils used as substrates during the test are reported in Table 1. The particle size fraction reveals a sand percentage of over 70% for the washed gold soil (SAL). According to the United States Department of Agriculture (USDA) textural triangle, SAL has a predominantly sandy texture dominated by coarse sand, in contrast to soil under natural vegetation (SSVN). Although electrical conductivity is high in the soil under natural vegetation (113.7 µS cm^{-1} vs. 22.6 for the washed gold soil), it remains below the threshold of 500 µS cm^{-1} according to Durand's scale, so these soils studied are not saline. Values for organic matter, carbon, nitrogen, phosphorus, potassium and calcium are higher on SSVN than on SAL. The pH of the soil under natural vegetation tends towards neutral (pH = 6.779), and the pH of the washed gold soil is slightly acidic (pH = 5.509).

Table 1. Physico-chemical characteristics of substrates prior to test set-up

Parameters		Type of growing medium	
		SSVN	SAL
Elements > 2mm	Concretion	0.258	5.598
Granulometry 5 fractions (%)	Clay ≤ 2 µm	3.01	0.07
	Fine silt 2 to 20µm	19.17	2.35
	Coarse silt 20 µ to 50µm	13.92	3.19
	Fine sand 50 to 200 µm	28.92	10.18
	Coarse sand 200 to 2000 µm	32.84	82.28
Organic matter (%)	Organic matter	3.12	0.17
	Carbon C	1.81	0.1
	Total nitrogen N	0.257	0.023
	C N^{-1}	7.043	4.348
Phosphorus (mg kg^{-1})	Assimilable (P) (mg kg^{-1})	3.18	1.377
Adsorbent complex (méq $100g^{-1}$)	Calcium (Ca)	2.374	1.063
	Potassium (K)	0.07	0.03
	Sodium (Na)	0.182	0.227
Salinity	Elect. conductivity 1 5^{-1} (µS cm^{-1})	113.7	22.6
pH (1 2.5^{-1})	Water	6.759	5.509

SSVN: soil under natural vegetation; SAL: washed gold soil

3.2 Mycorrhization of maize

The presence of mycorrhizal structures (arbuscular, vesicles, hyphae or appressorium) was observed at 30th days after sowing (DAS) with the pure AMF strain. The average mycorrhization frequency was statistically identical $P = 0.09$ (30th DAS) and $P = 0.18$ (60th DAS), irrespective of the soil type used, throughout the trial period. It varied from 30th DAS to 60th DAS from 55.25 % to 57.17 % for SSVN and from 47.13 % to 56.09 % for SAL over the same period (Table 2). The mycorrhization intensities associated with these frequencies are respectively 12.98 % to 32.33 % for SSVN and 13.70 % to 28.72 % for SAL. These mycorrhization intensities are statistically identical $P = 0.16$ (30th DAS) and $P = 0.08$ (60th DAS) on all soils during the trial. Analysis of variance showed no significant difference ($P = 0.15$ (30th DAS) and $P = 0.22$ (60th DAS)) in the shrub quality of the maize cortex in relation to soil type at the same time (Table 2).

Table 2. Effect of substrate type on mycorrhization in maize

Soil type	Mycorrhization frequency (%)		Mycorrhization intensity (%)		Shrub quality (%)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
SSVN	55.25±3.38 a	57.17±5.17a	12.98±1.13 a	32.33±2.26 a	15.68±1.22 a	28.91±2.01 a
SAL	47.13±4.73 a	56.09±3.33 a	13.70±1.09 a	28.72±1.44 a	18.22±0.89 a	26.23±1.37 a
P-value	0.09	0.18	0.16	0.08	0.15	0.22
CV (%)	14.35	13.22	17.44	13. 45	11.41	16.45

SSVN: soil under natural vegetation; SAL: washed gold soil; DAS: day after sowing. Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

However, plants in pots inoculated with AMF showed identical and significantly higher frequencies than those not mycorrhized (Table 3). Control plants without inoculum and those whose substrates had been amended revealed the presence of mycorrhizal structures in their root cortex as early as 30th DAS. Mycorrhization intensities were significantly identical between inoculated plants and significantly different from plants without inoculation ($P = 5.84.10^{-7}$ (30th DAS) and $P = 4.88.10^{-6}$ (60th DAS)).

Table 3. Effect of AMF inoculation on maize mycorrhization parameters

	Mycorrhization frequency (%)		Mycorrhization intensity (%)		Shrub quality (%)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Control	6.33±0.54 c	7.67±0.66 c	2.11±0.07 c	2.73±0.11 b	1.44±0.07 c	2.08±0.04 b
NPK+Urea	5.77±0.42 c	8.45±0.74 c	1.45±0.05 c	3.44±0.08 b	1.67±0.03 c	3.65±0.12 b
AMF	66.55±0.72 a	73.62±0.53 a	24.66±0.19 b	41.43±0.45 a	35.22±0.38 a	38.48±0.41 a
AMF+NPK+Urea	27.36±0.19 b	33.43±0.34 b	37.12±0.27 a	45.67±0.38 a	22.36 ±0.25b	27.50±0.21 a
P-value	$1.23\ 10^{-6}$	$3.66\ 10^{-4}$	$5.84\ 10^{-7}$	$4.88\ 10^{-6}$	$3.29\ 10^{-4}$	$3.12\ 10^{-3}$
CV (%)	16.88	18.66	18.55	21.22	17.26	16.45

Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

3.3 Influence of *G. mosseae* on germination rate

Maize seed germination was observed for 5 days after sowing. At 5th DAS, investigations showed that all the seeds sown had germinated. The germination rate was 100%. Inoculation with *G. mosseae* had no significant effect on maize seed germination.

3.4 Effect of soil and *G. mosseae* inoculation on maize growth parameters

The results show that the best performances were linked to collar diameter (0.51 ± 0.13 cm at 30th DAS and 0.60 ± 0.14 cm at 60th DAS), plant height (49.12 ± 13.35 cm at 30th DAS and 116.95 ± 26.09 cm at 60th DAS), number of leaves (5.66 ± 1.60 cm at 30th DAS and 8,91 ± 1.41 cm at 60th DAS), leaf length (55.45 ± 13.28 cm at 30th DAS and 59.34 ± 15.42 cm at 60th DAS) and leaf width (2.62 ± 0.61 at 30th DAS and 3.11 ± 0.88 cm at 60th DAS) were obtained with soils under natural vegetation (Tables 4 and 5). The results also show that plants in pure *G. mosseae* treatment record the best diameter, height, number of leaves, leaf length and leaf width (Tables 6 and 7).

Table 4. Effect of soil type on maize growth parameters

Soil type	Diameter at collar (cm)		Height (cm)	
	30 DAS	60 DAS	30 DAS	60 DAS
SSVN	0.51±0.13 a	0.60±0.14 a	49.12±13.35 a	116.95±26.09 a
SAL	0.34±0.10 b	0.36±0.10 b	32.70±11.38 b	54.72±24.32 b
P-value	$1.49\ 10^{-7}$	$2.58\ 10^{-14}$	$2.60\ 10^{-7}$	$4.27\ 10^{-14}$
CV (%)	21.22	15.09	22.53	22.1

SSVN: soil under natural vegetation; SAL: washed gold soil. Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

Table 5. Effect of soil type on maize growth parameters

Soil type	Number of leaves (cm)		Leaf length (cm)		Sheet width (cm)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
SSVN	5.66±1.60 a	8.91±1.41 a	55.45±13.28 a	59.34±15.42 a	2.62±0.61 a	3.11±0.88 a
SAL	3.41±01.21 b	6.12±1.16 b	37.09±6.35 b	33.38±9.67 b	1.62±0.35 b	1.90±0.44 b
P-value	$5.10\ 10^{-10}$	$1.39\ 10^{-09}$	$1.67\ 10^{-10}$	$9.52\ 10^{-13}$	$1.03\ 10^{-11}$	$9.51\ 10^{-12}$
CV (%)	21.11	16.45	16.82	19.05	17.09	18.07

SSVN: soil under natural vegetation; SAL: washed gold soil. Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

Table 6. Effect of mycorrhizal inoculation on maize growth parameters

	Diameter at collar (cm)		Height (cm)	
	30 DAS	60 DAS	30 DAS	60 DAS
Control	0.44±0.10 b	0.47±0.14 b	41.50±10.21 b	92.00±45.75 b
NPK+Urea	0.35±0.12 c	0.38±0.16 c	38.16±15.57 b	70.19±42.62 c
AMF	0.55±0.17 a	0.63±0.19 a	54.08±10.30 a	107.66±39.81 a
AMF+NPK+Urea	0.36±0.08 bc	0.44±0.08 bc	29.91±12.46 c	73.50±19.91 c

P-value	$1.44\ 10^{-5}$	$7.12\ 10^{-9}$	$1.77\ 10^{-6}$	$4.30\ 10^{-5}$
CV (%)	21.22	15.09	22.53	22.10

Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

Table 7. Effect of mycorrhizal inoculation on maize growth parameters

	Number of leaves (cm)		Leaf length (cm)		Sheet width (cm)	
	30 DAS	**60 DAS**	**30 DAS**	**60 DAS**	**30 DAS**	**60 DAS**
Control	5.00±1.70 b	7.25± 2.09 b	49.19± 15.17 b	50.55± 18.17 b	2.16±0.62 b	2.46±0.96 b
NPK+Urea	3.75±1.48 c	6.90± 1.65 b	41.30± 9.04 b	37.30± 18.68 c	1.77± 0.66 c	2.17±0.50 b
AMF	6.08±1.31 a	8.41± 2.06 a	56.50± 13.12 a	57.75±19.97 a	2.64± 0.77 a	3.10±1.34 a
AMF+NPK+Urea	3.33±1.43 c	7.50± 1.66 ab	38.11± 10.67 c	39.86±7.31 c	1.89± 0.48 c	2.30±0.30 b
P-value	$3.53\ 10^{-8}$	0.0312	$1.42\ 10^{-6}$	$2.03\ 10^{-6}$	$5.14\ 10^{-6}$	$3.61\ 10^{-5}$
CV (%)	21.11	16.45	16.82	19.05	17.09	18.07

Means followed by the same letter in the same column do not differ significantly at the 5% threshold.

3.5 Effect of soil type and *G. mosseae* inoculation on maize productivity parameters

The results show that poor performance in terms of spike insertion height, spike length, dry above-ground biomass, dry spike weight, number of dry seeds, dry seed weight and stalk weight was recorded at the SAL level (Tables 8 and 9). The results in Tables 9 and 10 show that the best performances were obtained for ear number (1.58 ± 0.51 cm at 60th DAS), panicle insertion height (94.50 ± 32.87 cm at 60th DAS), ear length (4.37 ± 1.35 cm at 90th DAS), ear diameter (3.31 ± 1.03 cm at 90th DAS), dry above-ground biomass (10.75 ± 9.04 g at 90th DAS), number of dry seeds (16.83 ± 7.62 at 90th DAS) and stalk weight (2.26 ± 0.80 g at 90th DAS) were obtained with the AMF treatment. The AMF+NPK+Urea combination performed better in terms of ear insertion height (49.66 ± 18.86 cm at 60th DAS), dry ear weight (7.66 ± 2.18 g at 90th DAS) and dry seed weight (7.91 ± 2.46 g at 90th DAS) than the control and NPK+Urea treatments, which performed significantly worse (Tables 10 and 11).

Table 8. Effect of soil type on maize productivity parameters

Soil type	Number of ears	Height at panicle insertion (cm)	Height of finial insertion (cm)	Ear length (cm)	Ear diameter (cm)
	60 DAS	**60 DAS**	**60 DAS**	**90 DAS**	**90 DAS**
SSVN	1.20±0.41 a	100.7±24.5 a	40.37± 13.94 a	4.07±1.10 a	2.40±1.11 a
SAL	1.22±0.41 a	57.25±24.94 b	40.04±18.22 a	3.20±0.50 b	2.22±0.63 a
P-value	0.84492	$7.04\ 10^{-9}$	0.907	$5.36\ 10^{-7}$	0.222
CV (%)	30.08	26.07	24.53	13.83	21.64

Table 9. Effect of soil type on maize productivity parameters

Soil type	Dry above-	Dry ear	Number Dry	Dry seed	Burst

	ground biomass (g)	weight (g)	seeds	weight (g)	weight (g)
	90 DAS	**90 DAS**	**90 DAS**	**90 DAS**	**90 DAS**
SSVN	10.08±6.74 a	6.12±2.86 a	13.42±7.37 a	4.78±3.43 a	2.05±0.64 a
SAL	3.62±2.67 b	3.79±1.56 b	9.75±3.89 b	3.77±2.13 b	1.48±0.58 b
P-value	$1.65\ 10^{-8}$	$2.84\ 10^{-9}$	0.000918	0.023016	0.000148
CV (%)	46.36	21.43	30.62	34.67	26.42

SSVN: soil under natural vegetation; SAL: washed gold soil. Means followed by the same letter in the same column do not differ significantly at the 5% threshold according to the PPDS test.

Table 10. Effect of mycorrhizal inoculation on maize productivity parameters

	Number of ears	Height at panicle insertion (cm)	Height of finial insertion (cm)	Ear length (cm)	Ear diameter (cm)
	60 DAS	**60 DAS**	**60 DAS**	**90 DAS**	**90 DAS**
Control	1.08±0.28 b	80.92±40.77 a	33.25±15.66 b	3.79±0.49 b	2.06±0.26 b
NPK+Urea	1.20±0.39 b	61.33±32.48 b	31.08±5.31 b	2.85±0.73 c	1.73±0.42 b
AMF	1.58±0.51 a	94.50±32.87 a	46.83±13.51 a	4.37±1.35 a	3.31±1.03 a
AMF+NPK+Urea	1.00±0.00 b	79.16±15.73 a	49.66±18.86 a	3.54±0.39 b	2.12±0.74 b
P-value	0.00191	0.00382	$2.29\ 10^{-5}$	$9.92\ 10^{-8}$	$7.92\ 10^{-9}$
CV (%)	30.08	26.07	24.53	13.83	21.64

Table 11. Effect of mycorrhizal inoculation on maize productivity parameters

	Dry above- ground biomass (g)	Dry ear weight (g)	Number of dry seeds	Dry seed weight (g)	Stalk weight (g)
	90 DAS	**90 DAS**	**90 DAS**	**90 DAS**	**90 DAS**
Control	9.25±3.76 a	3.92±0.90 c	9.33±2.10 b	3.15±2.16 bc	1.54±0.39 b
NPK+Urea	4.41±2.35 b	2.75±0.96 d	5.58±1.83 c	2.00±0.56 c	1.20±0.25 b
AMF	10.75±9.04 a	5.50±2.61 b	16.83±7.62 a	4.04±1.64 b	2.26±0.80 a
AMF+NPK+Urea	3.00±2.95 b	7.66±2.18 a	14.58±3.08 a	7.91±2.46 a	2.06±0.55 a
P-value	$3.89\ 10^{-7}$	$2.57\ 10^{-13}$	$3.34\ 10^{-9}$	$1.99\ 10^{-11}$	$5.2\ 10^{-6}$
CV (%)	46.36	21.43	30.62	34.67	26.42

SSVN: soil under natural vegetation; SAL: washed gold soil. Means followed by the same letter in the same column do not differ significantly at the 5% threshold according to the PPDS test.

4. DISCUSSION

The study has shown that washed gold-bearing soils are sandy and poor in organic and mineral matter essential for plant growth and development. This result was also demonstrated by [20], who showed that the deterioration index in organic matter, phosphorus, potassium and calcium exceeds 60 % on gold-bearing soils in southwestern Nigeria. Bohbot [21] showed that artisanal gold mining leads to lasting environmental degradation through the loss of arable land in Burkina-Faso, and water and soil pollution.

In this study, gold-rich soils showed poor agronomic performance compared with soils under natural vegetation. The effectiveness of soils under natural vegetation in improving the agronomic performance of maize is of scientific interest. Natural vegetation can play an important role in preserving soil fertility by providing a permanent cover that reduces erosion and improves water storage. A study carried out in Brazil compared three types of system, including a conventional system with deep ploughing, a no-till system with intercropping

(maize + legumes) and an agroforestry system with fruit trees associated with a vegetable crop [22]. Results showed that average yields were higher in the agroforestry system (11,000 kg/ha) than in the other two systems (9,500 kg/ha for the no-till system and 8,400 kg/ha for the ploughed system). This system also had a higher organic matter content and a better physical soil structure. Environmental responsibility with ecologically sustainable practices should be developed in this era of sustainable development with a view to restoring terrestrial ecosystems while ensuring sustainable agriculture.

The study showed that the use of the mycorrhizal fungus *G. mosseae*, in single inoculation or in combination with fertilizers on gold-bearing soils, resulted in satisfactory agronomic performance and good corn grain yields. Similar results were demonstrated by Malonda et al. [23], who found that AMF improved soil structure, increased soil phosphorus to 7.5 %, nitrogen to 4 % and carbon to 13 %, and increased yields. Haro and Sanon [24] have also shown that inoculation with AMF considerably increases the aerial and root biomass of sesame. Indeed, the symbiotic association of AMF with plant roots improves the plant's water and mineral nutrition [25]. The association of AMF with maize roots in this study enabled a significant improvement in agronomic performance through increased water and nutrient uptake [26]. Various studies have demonstrated that soil inoculation with AMF spores can significantly increase crop yields under certain unfavorable environmental conditions [27] as in the case of structurally degraded soils found at gold mining sites in the Central Region of Togo. The positive effects on plant growth and health can also translate into a significant mobilization of essential nutrients such as phosphorus, potassium and nitrogen in the soil [28–30]. AMF makes a lasting contribution to the restoration of degraded soils [31–33].

5. CONCLUSION

The study provided information on the status of gold-bearing soils in Togo. It demonstrated that the use of AMF *G. mosseae* as a biofertilizer can be beneficial for plant growth and development under washed gold soils. Extension and adoption of the use of AMF can be a major component of sustainable agriculture. The present study represents an opportunity for the implementation of ecological and organic farming practices among farmers in areas degraded by intensive mining activities in Togo.

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 the writing or editing of manuscripts.

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