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Successful use of biofertilizers in sub-Saharan Africa : how soil fertility level constitutes its first step

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Abstract

This study assessed the potentials of biological and foliar fertilizers on cowpea growth and yield in the southern Guinea savannah of Nigeria. Microbial inoculants (RACA6, Rhizatech and Eco-T) were used with two foliar fertilizers (Agroleaf high P and Agrolyser). Shoot dry weight as recorded under TSP, RACA6+TSP, Agroleaf high P and Reference treatment ranged from 40.57 to 46.59 g plant^{-1}. Microbial inoculant effect on shoot dry weight was not significantly different from that of inorganic fertilizers. Combined application of RACA6+Rhizatech+Agrolyser significantly improved shoot P content. Foliar fertilizer treatments had no significant influence on cowpea grain yield which varied from 11.28 to 19.63 g plant^{-1}. The grain yield under Agroleaf high P and Rhizatech were 18.41 and 19.63 g plant^{-1} respectively. Grain yield of 16.32 g plant^{-1} was recorded under the reference treatment while the grain yield of 13.96 g plant^{-1} was observed under TSP. Thus, the use of microbial inoculants and foliar fertilizers could potentially enhance grain legumes production among smallholder farmers' field. Through biofertilizer usage, environmental safety is assured thereby reducing N runoff threat.

Keywords : *Cowpea, Microbial Inoculant, Foliar feeding, Savannah, Soil health.*

Résumé

Utilisation effective des biofertilisants en Afrique subsaharienne : comment le niveau de fertilité des sols constitue sa première étape

Cette étude a évalué les potentiels des engrais biologiques et foliaires sur la croissance et le rendement du niébé au sud de la savane Guinéenne au Nigeria. Les inoculants microbiens (RACA6, Rhizatech et Eco-T) ont été utilisés avec deux engrais foliaires (Agroleaf high P et Agrolyser). La biomasse aérienne sèche sous TSP, RACA6+TSP, Agroleaf high P et le traitement de référence variait de 40,57 à 46,59 g plant^{-1}. L'effet de l'inoculation n'était pas significativement différent de celui des engrais inorganiques sur la biomasse aérienne sèche. L'application combinée de RACA6+Rhizatech+Agrolyser a considérablement amélioré la concentration en P de la biomasse aérienne. Les traitements d'engrais foliaires n'ont eu aucune influence significative sur le rendement des grains de niébé qui variait de 11,28 à 19,63 g plan^{t-1}. Le rendement en grains sous Agroleaf high P et Rhizatech était de 18,41 et 19,63 g plant^{-1}, respectivement. Le rendement en grains de 16,32 g plant^{-1} a été enregistré sous le traitement de référence, tandis que celui de 13,96 g plant^{-1} a été observé sous TSP.

Ainsi, l'utilisation d'inoculants microbiens et d'engrais foliaires pourrait potentiellement améliorer la production de légumineuses à grains dans les champs des paysans. A travers l'utilisation des biofertilisants, la sécurité environnementale est assurée, réduisant ainsi la menace de ruissellement de l'azote.

Mots-clés : *Niébé, Inoculant microbien, Nutrition foliaire, Savane Guinéenne, Santé du sol.*

1. Introduction

Sub-Saharan Africa needs to produce more food to nourish its exponential growing population. In fact, approximately 27.4 % of the population in Africa was classified as severely food insecure in 2016 [1]. Thus, it is worrisome that food insecurity is on the rise, specifically in sub-Saharan Africa. According to several reports [2], the most important constraint limiting crop production in SSA, among smallholder farmers, is soil fertility decline. Majority of farming systems in this region do export more nutrient from farm land than it is applied from external inputs [3]. Smallholder famers in most SSA countries lack financial strength and this coupled with failure in agricultural input subsidies, use of chemical fertilizer among them declined to less than 10 kg ha^{-1} [4, 5]. Increasing usage of microbial fertilizer have however raised some hope in food production. In fact, in the last decade, soil microbial-based fertilizers have tremendously been introduced to farmers. Research programmes confirms the importance of using such biofertilizer in soil fertility improvement and crop production. Microorganisms commonly used as biofertilizers component are nitrogen fixers (N-fixers), potassium solubilizer (K-solubilizers) and phosphorus solubilizer (P-solubilizers), or with the combination of fungi [6, 7]. As well, soil microorganisms are involved in plant biotic and abiotic stress resistance enhancement [8]. Biological nitrogen fixation (BNF), is seen as a key source of nitrogen for resource-poor farmers incapable of accessing N fertilizer and constitutes therefore one of the potential alternative solutions to increase nitrogen budget in the soil [9]. Moreover, BNF, as well as other biofertilizers, is an environmental-friendly mean for sustainable farming and cheap technology smallholder farmers. However, biofertilizers (bacterial or fungal) efficiency could be reduced or even annulled by many soil environmental conditions, autochthonous microorganisms and as well the effect of farmers' practices [7]. Factors limiting field evaluation of biofertilizer are mostly related to the dose of application and microbial rhizocompetence, soil pH, soil organic matter and moisture content, crop specificity and pesticide application. A variety of biofertilizers produced all over the world are made available in different markets to the SSA farmers [10]. This study aimed at evaluating the efficacy of biological and foliar fertilizers in farmers' fields.

2. Material and methods

2-1. Site description

Southern Guinea Savannah (SGS) is among of the zones where grain legumes are commonly grown in Nigeria. The SGS in Nigeria is located between the latitudes 7°4' and 8°7' N and longitudes 4°1' and 12°2' E [11]. The soils are composed of Luvisols, Acrisols, Ferralsols and Lithosols [12]. The growth length is 181-210 days. The annual rainfall varies from 1000 to 1500 mm [11]. The wet season starts from April to October with peak rainfall in September [13]. Mokwa local government area is situated in the south senatorial district of Niger State. The characteristic vegetation of Mokwa zone is open deciduous woodland reaching a height of around 15 m with a dense field layer of grasses up to 2 m. The soils are deep undifferentiated red ferrisols, having a sandy surface and clay content gradually increasing with depth to a B horizon [14].

2-2. Plant material

IT89KD-288 is an improved cowpea variety developed by the International Institute of Tropical Agriculture (IITA). IT89KD-288 (also called SAMPEA-11) is medium maturing cultivar that is recommended for Nigeria [15] and well adapted to the southern Guinea savannah [16]. It is a determinate high yielding variety (1.0 and 1.2 t ha^{-1}) with high-quality grains. The variety is resistant to septoria leaf spot, scab and bacterial blight, nematodes and tolerant to *Striga gesnerioides*, and it is also considered as good source to breed new varieties resistant to Cercospora [17].

2-3. Microbial inoculants application

Two commercial fungi inoculants [Rhizatech (Dudutech Ltd., Kenya) et Eco-T (Plant Health Products (Pty) LTD, South Africa)] and one laboratory produced rhizobial inoculant (RACA6 from IITA, Ibadan, Nigeria) were soil microbial-based inoculants used in the experiment. Rhizatech contains Spores and mycelia fragments of AMF and Eco-T is a *Trichoderma harzianum* strain Rfai KRL AG2 based product. Before planting, cowpea seeds were coated with RACA6 and Eco-T while Rhizatech was introduced the planting hole at seeding. Soil inoculation procedure was as follows: 50 g of Rhizatech was thoroughly mixed with 500 g of soil collected directly from the field. Thereafter, a sample of the mixture was taken and introduced into the holes prior to sowing of seeds.

2-4. Foliar and soil apply fertilizers application

Agroleaf high P and Agrolyser, two foliar fertilizers, were sprayed three times under high pressure at 3, 6 and 8 weeks after sowing (WAS). Agroleaf high P (NPK + micronutrients) and Agrolyser micronutrient fertilizer (10 micronutrients) are foliar fertilizer formulations produced by Scotts Company (Ohio, USA), and Cybernetics Ltd. (Nigeria), respectively. Triple superphosphate (TSP, 46 % P_2O_5) and urea (46 % N), both were applied on the soil at rates of 30 kg P_2O_5 ha^{-1} and 120 kg N ha^{-1}, respectively. The application of TSP was done once at planting while urea was applied in three splits (at sowing, 3 WAS and at flowering). The experiment was carried out in a randomized complete block design with four replications representing four farmers field in the agroecological zone of southern Guinea savannah.

2-5. Data collection

2-5-1. Plant growth parameters and nutrients content

The sampling of the plants was done at 8 WAS. Plants were harvested; shoot, root and nodules were separated. Shoot and root were dried for 72 hours at 60 °C to determine plant root and shoot dry matter accumulation using electronic sensitive balance METTLER TOLEDO (France) with a precision of 0.0001 g. Afterwards, stem and leaves were ground-milled separately to pass 0.4 mm sieve and were analyzed for N and P concentration.

2-5-2. Grain yield and 100-seed weight

At harvest, the grain yields were collected from the net plot size (3.75 m^2) to estimate the grain yield per plant. After harvesting, one hundred seeds were randomly selected and weighed. These seeds were dried at 72 h at 60 °C to determine the seed dry weight. The moisture content of the 100-seed weight was then used to estimate the dried weight of the grain.

2-5-3. Statistical analysis

The statistical analysis was carried out using (write name of package in full) SAS version 9.2. An analysis of variance was conducted at the probability level $\alpha = 0.05$. Further analyses were conducted for multiple mean comparisons with Duncan's Multiple Range Test (MRT).

3. Results

3-1. Soil chemical and physical properties in Mokwa at planting

The chemical analysis of soils samples showed that the soil is neutral with a pH = 7.1. The OC was 6.38 g kg^{-1} with a mean value of cation exchange capacity (CEC) equal to 5.89 $Cmol_c$ g kg^{-1}. Available P varied from 3.96 to 31.03 mg kg^{-1} while total N ranged from 0.41 to 0.56 g kg^{-1}. The physical analysis showed that the soil is sandy loamy ***(Table 1)***.

Table 1 : *Soil chemical and physical parameters of the sites at sowing*

Farmers	Units	Mamman	Idris	Nmadu	Wangwa	Means
$pH_{(H2O)}$ 1:1		6.5	7.8	8.2	6	7.1
OC	g.kg^{-1}	7.14	6.04	5.70	6.63	6.38
N	g kg^{-1}	0.56	0.42	0.41	0.51	0.48
Mehlich P	mg kg^{-1}	9.98	22.26	31.03	3.96	16.81
Ca	mg kg^{-1}	3.58	6.09	4.62	3.07	4.34
Mg	mg kg^{-1}	0.87	1.34	1.69	1.06	1.24
K	mg kg^{-1}	0.21	0.13	0.29	0.15	0.19
Na	mg kg^{-1}	0.12	0.10	0.12	0.11	0.11
Exch. Acidity	Cmol kg^{-1}	0.00	0.00	0.00	0.00	0.00
ECEC	Cmol kg^{-1}	4.78	7.67	6.71	4.38	5.89
Zn	Cmol kg^{-1}	2.02	1.52	1.69	1.03	1.56
Cu	Cmol kg^{-1}	1.46	2.43	0.97	1.94	1.70
Mn	Cmol kg^{-1}	144.32	136.97	148.65	165.53	148.87
Fe	Cmol kg^{-1}	49.00	70.00	62.00	76.00	64.25
Sand	g kg^{-1}	744	764	784	684	744
Silt	g kg^{-1}	140	120	100	180	135
Clay	g kg^{-1}	116	116	116	136	121
Soil texture				Sandy Loam		

3-2. Soil effect on plant yields and nutrients concentration

The ANOVA did not reveal any significant effect of soil on cowpea shoot dry weight ***(Table 2)***. However, the ANOVA showed that the soils have significantly influenced shoot nitrogen and phosphorus concentration, grain yield and 100-seeds weight. The highest grain yields of 19.24 and 18.31 g $plant^{-1}$ were recorded from the field of Idris and Wangwa. These fields had the highest shoot P concentration of 1.62 and 1.60 g kg^{-1} respectively for Idris and Wangwa.

Table 2 : *Effect of soil on cowpea shoot dry weight, grain yield and nutrients concentration*

Farmers	Sdwtp (g plant^{-1})	Gdwtp (g plant^{-1})	100-seeds (g plant^{-1})	N (g kg^{-1})	P (g kg^{-1})
Mamman	31.50 a	14.74 b	17.06 c	22.48 b	1.10 b
Idris	29.54 a	19.24 a	18.05 b	22.16 b	1.62 a
Nmadu	40.57 a	8.06 c	20.39 a	22.94 b	1.04 b
Wangwa	37.30 a	18.31 ab	20.21 a	25.97 a	1.60 a

Sdwtp : shoot dry weight per plant. Gdwtp: grain dry weight per plant

3-3. Products' effects on cowpea shoot dry weights, N and P concentrations

With the application of microbial inoculants and foliar fertiliser, cowpea IT89D-288 shoot dry weight ranged from 22.38 to 46.59 g per plant. Eco-T application produced the lowest shoot dry weight ***(Figure 1)***. Apart from RACA6+TSP, combined applications of RACA6 either with foliar fertilizers or fungi inoculants (AMF and Eco-T) depressed the shoot dry weight compared to shoot dry weight observed under single inoculant application. The highest shoot dry weight of 46.59 g plant^{-1} was produced by the application of 30 kg P ha^{-1}. It was followed by the treatments of RACA6+TSP (42.65 g plant^{-1}) and Agroleaf high P (41.23 g plant^{-1}), respectively. The shoot dry weights of the following treatments 30 kg P ha^{-1}, RACA6+TSP and Agroleaf high P were relatively higher than the shoot dry weight of the Reference plot (40.57 g plant^{-1}).

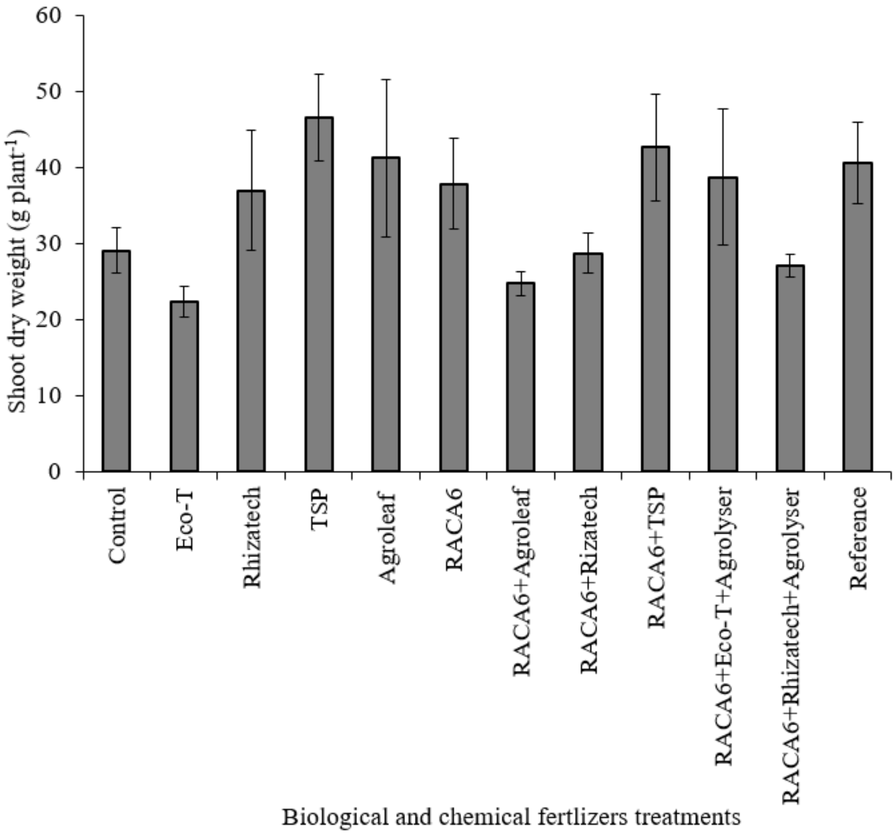

Figure 1 : *Effect of biological and chemical fertilizer on cowpea shoot biomass production at 8 WAS in Mokwa (errors bars indicate standard errors of means)*

The single inoculation of the AMF inoculant Rhizatech, the rhizobial inoculant RACA6 and the co-inoculation of both biofertilizers slightly favoured increase in cowpea shoot N concentration by 4 %, 7 % and 5 %, respectively ***(Table 3)***. The different treatments also significantly influenced the cowpea shoot P concentration at 8 WAS ***(Figure 2)***. The highest cowpea shoot P concentration was recorded from the plants treated with a combination of RACA6, Rhizatech and Agrolyser. The application of Agroleaf high P gave the lowest shoot P concentration.

Table 3 : *Cowpea shoot N concentration as influenced by biological and chemical fertilizers treatments at 8 WAS in Mokwa*

Treatments	N concentration	Relative response (%)
Control	23.7	-
Eco-T	21.35	-10
Rhizatech	24.65	4
TSP (30 kg P ha^{-1})	23.35	-1
Agroleaf	22.45	-5
RACA6	25.35	7
RACA6 + Agroleaf	22.83	-4
RACA6 + Rhizatech	24.85	5
RACA6 + TSP	22.6	-5
RACA6 + Eco-T + Agrolyser	22.9	-3
RACA6 + Rhizatech + Agrolyser	23.75	0
Reference (120 kg N + 30 kg P ha^{-1})	22.85	-4

3-4. Grain yield and 100-seed weight

As shown in ***Table 4***, the application of the different treatments did not significantly influence cowpea grain yield. The grain yield per plant varied from 11.28 to19.63 g. The foliar fertilizer Agroleaf with the yield of 18.41 g $plant^{-1}$ and Rhizatech with 19.63 g $plant^{-1}$ produced higher yield than the Reference treatment which had 16.32 g $plant^{-1}$. The application of RACA6 alone or in combination failed to increase the cowpea grain yield significantly. The 100-seeds dry weight ranged between 18.15 g and 19.38 g. The highest seed dry weight was produced by the combined treatment of RACA6+Rhizatech+Agrolyser with 19.38 g and was followed by Agroleaf with 19.35 g. The combined application of RACA6 either with Agroleaf, Rhizatech or TSP did not increase the 100-seed dry weight.

Table 4 : *Effect of treatments on grain yield (g $plant^{1}$) and 100-seed (g) dry weight of cowpea in Mokwa*

Treatment	Grain yield	Relative response (%)	100-seed dry weight	Relative response (%)
Control	16.09	-	18.95	-
Eco-T	14.00	-13	18.9	0
Rhizatech	19.63	22	19.22	1
TSP (30 kg P_2O_5 ha^{-1})	13.96	-13	18.77	-1
Agroleaf	18.41	14	19.35	2
RACA6	11.28	-30	19.04	0
RACA6 + Agroleaf	14.62	-9	18.15	-4
RACA6 + Rhizatech	12.99	-19	18.45	-3
RACA6 + TSP	12.24	-24	18.49	-2
RACA6 + Eco-T+Agrolyser	15.99	-1	19.19	1
RACA6 + Rhizatech + Agrolyser	14.35	-11	19.38	2
Reference (120 kg N + 30 kg P_2O_5 ha^{-1})	16.32	1	19.26	2

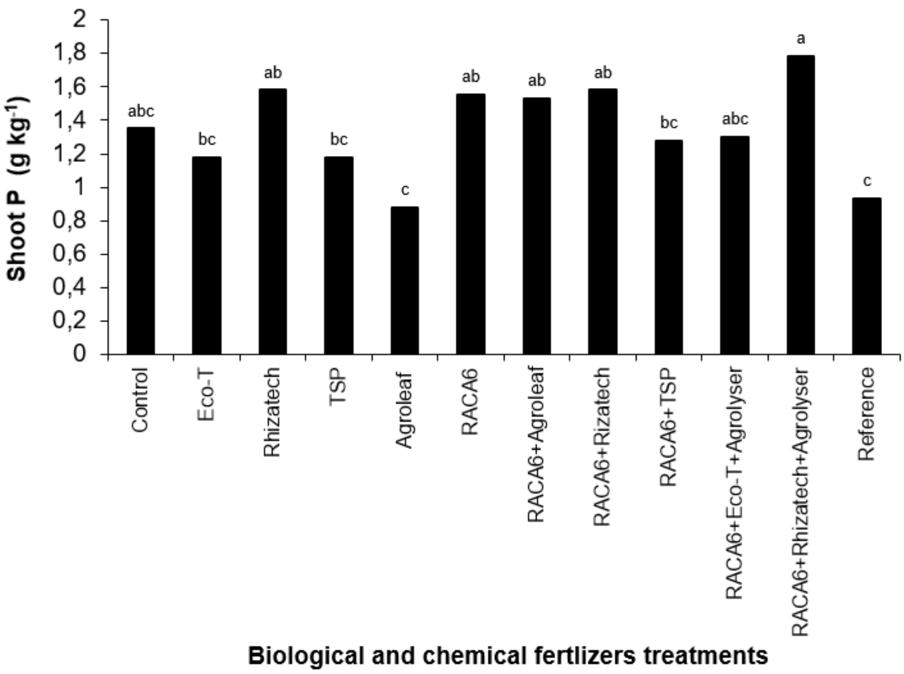

Figure 2 : *Effect of biological and chemical fertilizers on cowpea shoot P concentration at 8 WAS in Mokwa (Bar with the same letters are not statistically different according to Duncan's test at P = 0.5)*

4. Discussion

Being tolerant to a wide range of soil texture [18, 19], cowpea can also thrive on highly acid to slightly alkaline soils. From the soil analysis results, the soil pH of the farmers' fields used for the experiment varied from slightly acid to medium alkaline. Consequently, soil pH could not hamper cowpea IT89KD-288 variety growth. However, significant soil effect was recorded on grain yield, 100-seeds weight, shoot N and P concentration. The range of the weight of 100-seed follows the same trend of the one found by [20]. The mean weight of 100-seeds of 18.92 g recorded during this experiment was comprised between 17.04 g and 21.69 g observed respectively by [21, 22] with the same cowpea cultivar. The differences noticed on these variables might have resulted from some soil chemical whose content varied from one farm to other. Cowpea nutrient requirement varies among landraces and improved varieties. Due to its promiscuity to indigenous rhizobia, cowpea normally meets its N requirement through BNF. Next to N, P is often the most limiting nutrient for crop production. Regarding soil available P, the highest were recorded from the farm of Nmadu being 31.03 mg kg^{-1} followed by that of Idris with 22.2 mg kg^{-1}. The highest grain yield of 19.24 g was recorded in Idris's farm while the least was observed under Nmadu's farm. This observation could be due to higher soil pH (medium alkaline) as found in Nmadu's farm. In fact, soil pH plays a significant role in plant P-availability. Soils with pH values between 6 and 7.5 are perfect for P-availability; below or above this range pH limits P-availability to plants due to fixation by Al, Fe, or Ca [23]. Biofertilizer treatments which were associated with improved P uptake were also had the highest grain yield; grain yield of 19.63 and 18.41 g $plant^{-1}$ were recorded under Rhizatech and Agroleaf high P, respectively [24]. The reference and TSP (30 kg P ha^{-1}) treatments did not consequently improve cowpea yield. Based on this observation, improvement in cowpea P-uptake could result in enhanced grain yield. Furthermore, the effect of inherent chemical (pH, nutrient content) characteristics of the soil is the first parameter underling the effectiveness of microbial inoculants [7]. Consequently, the non-performance observed on some growth parameters could be explained by the negative effect of soil biotic and abiotic on the microbial inoculant agents [25].

5. Conclusion

The results from this study showed that the application microbial based fertilizer improved cowpea grain yield. Apart from BNF through which bacteria bring N from air into soil, most of the biofertilizer active agents are involved in facilitating resource acquisition for the plant. As shown in this experiment, Rhizatech, a mycorrhizal inoculant, improved significantly cowpea grain yield. The mechanism used by AMF is based on large soil volume soil exploration and capability of the hyphae to penetrate small pores. The direct consequence is mobilization of enough nutrients present in the soil for the plant. From this observation, further experiments need to be conducted to categorize soil regarding their potentials to respond favourably to biofertilizers.

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