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Research Application Summary

# Doubling soybean grain yield by enhancing biotic interactions and plant nutrition using beneficial microbes and plant bioactive materials for the benefit of farmers and sustainability of agro-ecosystems in sub-Saharan Africa

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## Abstract

Soybean plays vital roles in food and nutrition security while generating income for many smallholder farmers in sub -Saharan Africa (SSA). Nevertheless, production is partly constraint by poor and declining soil fertility. Chemical fertilizers are commonly used to mitigate this challenge, however, these chemicals are not readily accessible for many smallholder farmers, and their improper and continuous use increase production costs and may be harmful to biotic interactions in the rhizosphere that enable important plant functions. Sustainable management strategies are encouraged but understanding their role in soil biotic processes is vital for the proper functioning of soil ecosystems. Thus, field studies were conducted in two alternate seasons in Cameroon (August 2021 and March 2022) to evaluate the implications of 13 farm management strategies involving agrochemicals, beneficial microbes and plant bioactive materials on soil biotic interactions and soybean grain yield. The experiment was established as a Randomized Complete Block Design with thirteen treatments and four replications. Interestingly, soybean grain yield of plots treated with beneficial microbes, plant bioactive materials and agrochemicals doubled, beneficial microbes and plant bioactive materials significantly increased soil microbial biomass total root bacteria, and enzyme activities over the chemical and the untreated control treatments. The soil microbial biomass content was significantly harmed by agrochemicals when compared to the untreated control. These results highlight the importance of beneficial microbes and plant bioactive materials as sustainable management options to increase soybean grain yield, and integrating them in agro-ecosystems could be a holistic approach that is economically viable, resource-conserving, socio-culturally adaptable, and environmentally friendly.

**Keywords:** Beneficial microbes, Plant bioactive materials, Soybean, Sustainability, Yield

## Résumé

Le soja joue un rôle vital dans la sécurité alimentaire et nutritionnelle tout en générant des revenus pour de nombreux petits exploitants agricoles en Afrique subsaharienne (ASS). Néanmoins, la production est en partie limitée par une fertilité des sols pauvre et en déclin. Les engrais chimiques sont couramment utilisés pour atténuer ce problème, cependant, ces produits ne sont pas facilement accessibles pour de nombreux petits exploitants, et leur utilisation inappropriée et continue augmente les coûts de production et peut être nuisible aux interactions biotiques dans la rhizosphère qui permettent des fonctions végétales importantes. Les stratégies de gestion durable sont encouragées, mais la compréhension de leur rôle dans les processus biotiques du sol est essentielle pour le bon fonctionnement des écosystèmes du sol. Ainsi, des études de terrain ont été menées en deux saisons alternées au Cameroun (août 2021 et mars 2022) pour évaluer les implications de 13 stratégies de gestion agricole impliquant des produits agrochimiques, des microbes bénéfiques et des matériaux bioactifs sur les interactions biotiques du sol et le rendement en grains de soja. L'expérience a été établie en tant que dispositif en blocs complets randomisés avec treize traitements et quatre répétitions. Fait intéressant, le rendement en grains de soja des parcelles traitées avec des microbes bénéfiques, des matériaux bioactifs et des produits agrochimiques a doublé, les microbes bénéfiques et les matériaux bioactifs ont significativement augmenté la biomasse microbienne du sol, les bactéries totales des racines et les activités enzymatiques par rapport aux traitements chimiques et aux témoins non traités. La teneur en biomasse microbienne du sol a été significativement affectée par les produits agrochimiques par rapport au témoin non traité. Ces résultats soulignent l'importance des microbes bénéfiques et des matériaux bioactifs comme options de gestion durable pour augmenter le rendement en grains de soja, et leur intégration dans les agro-écosystèmes pourrait être une approche holistique économiquement viable, économisant les ressources, socioculturellement adaptable et respectueuse de l'environnement.

**Mots-clés :** Microbes bénéfiques, Matériaux bioactifs, Soja, Durabilité, Rendement

## Background

Soybean (*Glycine max* (L.) Merrill) is considered as the most important grain legume because of its high protein and oil content, making it a cheap substitute for expensive animal protein sources like meat and fish in sub-Saharan Africa (SSA) (Krishnan *et al*., 2018; Feng *et al*., 2019; Nzossié and Bring, 2020). It also has the ability to ameliorate the soil fertility status because of their ability to fix nitrogen and contribute to significant amount of soil available nutrients (Kebede, 2021; Ngosong *et al*., 2022).

The majority of the world's soybean is produced in Brazil and the United States of America, with an annual output of 121.8 million tons and 112.5 million tons, respectively (FAOSTAT, 2022). Unfortunately, Africa produces less than 1% of the global soybean (Cornelius and Goldsmith, 2019; FAOSTAT, 2022). Since 1961, soybean production has increased globally at an annual growth rate of 4.68%, with African production growing 48% faster at a rate of 6.84% annually (Cornelius and Goldsmith, 2019; FAOSTAT, 2022). The increase in total arable land area, rather than yield per unit area of arable land, is primarily responsible for the growth in production in Africa (Cornelius and Goldsmith, 2019; FAOSTAT, 2022). Like many Sub-Saharan countries, Cameroon relies heavily on smallholder farmers to cultivate soybeans. Nevertheless, Cameroon still imports GMO soybean meal worth CFAF 14 billion and 20,000 tons of soybeans worth roughly CFAF 10 billion every year (Ngosong *et al*., 2022). As a result, it is difficult to raise domestic production to fulfill consumers and agro-industrial demand.

By 2050, the world's population is forecast to expand from its present level of 8 billion to 9.7 billion, with a majority of this growth expected to take place in developing nations (UN DESA, 2019). Africa's present population of 1.4 billion people is projected to reach 2.5 billion by 2050, with SSA expected to account for the largest proportion of this increase (Bergaglio, 2017; UN, DESA, 2019). In order to feed this rapidly increasing population, there must be an increase in food production per unit area of cultivable land, yet soybean production in Cameroon and SSA continues to be threatened by poor and declining soil fertility (Ngosong *et al*., 2022). Unsustainable management practices like inappropriate use of agrochemicals, continuous cultivation and lack of proper cropping systems are responsible for huge yield gaps of over 60% between actual production and attainable potential which are exacerbating the already precarious global food insecurity challenges (Ngosong *et al*., 2022). Agrochemicals boost crop yield, but smallholder farmers in Cameroon and SSA do not have easy access to them, and their improper and continuous use increases production costs, breeds pest resistance, and has deleterious effects on the environment and humans. To narrow these enormous yield gaps, it is imperative to adopt sustainable management approaches such as the use of carefully selected beneficial microorganisms and plant bioactive materials with specific functions in arable systems that are tailored to the specific needs of farmers.

**Study Description**

This study was carried out from August to December 2021 and from April to August 2022, which represent two different planting seasons in Buea, Cameroon. The site is situated between longitudes 9º9’ to 9º22’ east of the Greenwich Meridian and latitudes 4º12’ and 4º31’ north of the equator. The site is located in the agro-ecological zone of the humid forest, with a mono-modal rainfall pattern and a rainy season from March to October. The average annual rainfall is between 3000 and 5000 mm, with a relative humidity of 85-90 % and the annual temperature is between 20 and 28 °C, with 900 to 1200 h of sunshine. The volcanic rocks that the loamy soils are generated from are predominately sand (59 %), silt (27 %), and clay (14 %).

The experiment was setup as a Randomized Complete Block Design (RCBD) with 13 treatments and four replications of each. Each replicate had thirteen (13) experimental plots making a total of 52 experimental plots for the entire experiment. The treatments include T1 – Control (no input), T2 – NPK (Chemical fertilizer) + LG (Lamida gold insecticide), T3 – PGPB 1 (*Bacillus* sp., *Arthrobacter* sp., *Paenibacillus* sp. and *Kosakonia radicincitans*) + EF (*Beauveria* sp. and *Trichoderma* sp.), T4 – PGPB 2 (*Bacillus* sp., *Arthrobacter* sp., *Paenibacillus* sp., *Kosakonia radicincitans* and *Bradyrhizobium japonicum*) + EF, T5 – PGBP 1 + P (*Piper guineense* extract), T6 – PGBP 2 + P, T7 – R (*Bradyrhizobium japonicum*) + P, T8 – R + EF, T9– M (*Mucuna cochinchinensis* extract) + P, T10 – M + EF, T11 – PGPB 1 + M + EF + P, T12 – PGPB 2 + M + EF + P, T13 – M + R + EF + P.

**Results**

There was a double fold increase in soybean grain yield for all treatments with beneficial microbes, plant bioactive materials and agrochemicals when compared to the untreated control ($P<0.05$). Interestingly, Beneficial microbes and plant bioactive materials significantly increased total root bacteria, soil microbial biomass and enzyme activities (phosphatase and urease) over the chemical and the untreated control treatments ($P<0.05$). The soil microbial biomass content was significantly harmed by agrochemicals when compared to the untreated control ($P<0.05$).

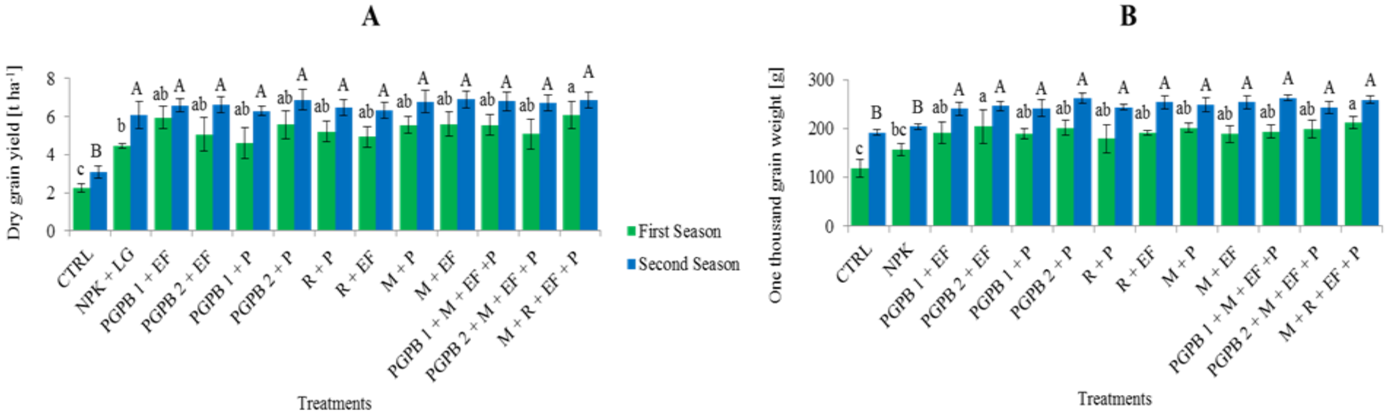


Figure 1. Effect of treatments on soybean dry grain yield (A) and 1000 grain weight (B) in the first (green bars) and second (blue bars) seasons (Mean ± SD). Bars with different lowercase and uppercase letters represent significant differences across treatments for the first and second seasons, respectively (Tukey's HSD, P<0.05). CTRL: No input, NPK: Chemical fertilizer, LG: Lamida gold insecticide, PGPB1: Plant growth promoting bacteria without rhizobium, EF: Endophytic fungi, PGPB2: Plant growth promoting bacteria + Rhizobium, R: Rhizobium, P: Piper plant extract, M: Mucuna plant extract.

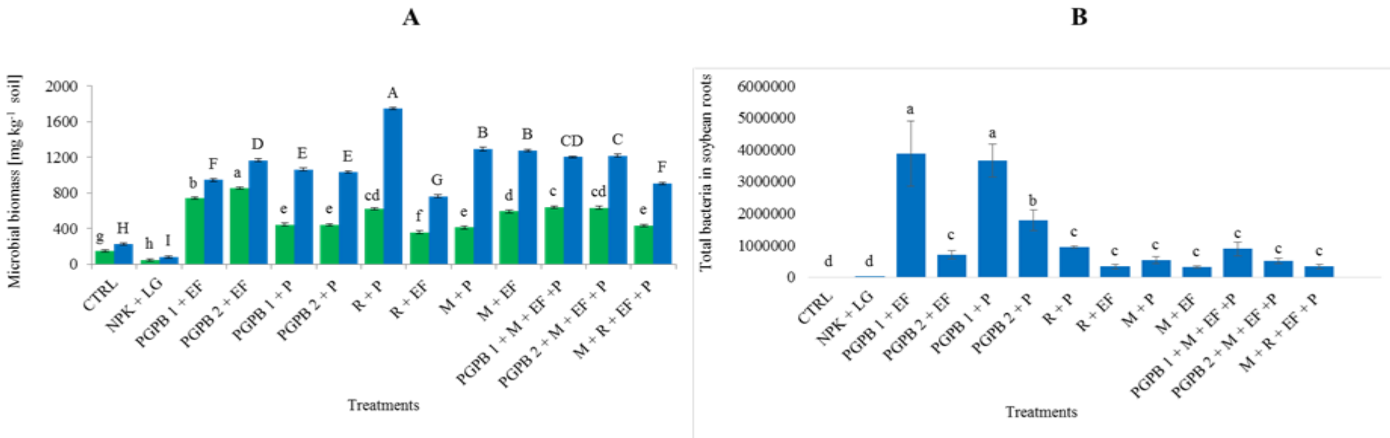


Figure 2. Effect of treatments on soil microbial biomass (A) and total root bacteria (B) relative to TEF reference gene and non-treated control (Mean ± SD) in the rhizosphere of soybean plants. Bars with different lowercase and uppercase letters represent significant differences across treatments for the first (green bars) and second (blue bars) seasons, respectively (Tukey's HSD, P<0.05). CTRL: no input, NPK: Chemical fertilizer, LG: Lamida gold insecticide, PGPB1: Plant growth-promoting bacteria without Rhizobium, PGPB2: Plant growth-promoting bacteria+Rhizobium, R: Rhizobium, EF: Endophytic fungi, P: Piper plant extract, M: Mucuna plant extract.

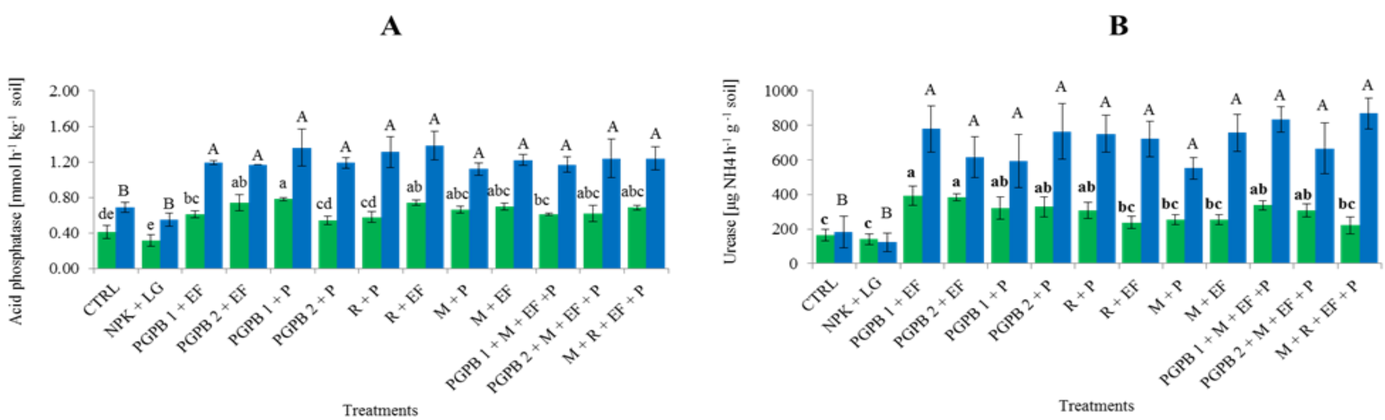


Figure 3. Effect of treatments on acid phosphatase (A) and urease (B) in the rhizosphere of soybean plants. Bars (Mean ± SD) with different lowercase and uppercase letters represent significant differences across treatments for the first (green bars) and second (blue bars) seasons, respectively (Tukey's HSD, P<0.05). CTRL: no input, NPK: Chemical fertilizer, LG: Lamida gold insecticide, PGPB1: Plant growth-promoting bacteria without Rhizobium (Bacillus sp., Arthrobacter sp., Paenibacillus sp. and Kosakonia radicincitans), PGPB2: Plant growth-promoting bacteria + Rhizobium (Bacillus sp., Arthrobacter sp., Paenibacillus sp., Kosakonia radicincitans and Bradyrhizobium japonicum), R: Rhizobium (Bradyrhizobium japonicum), EF: Endophytic fungi (Beauveria sp. and Trichoderma sp.), P: Piper plant extract, M: Mucuna plant extract.

## Discussion

Farm management strategies have a significant impact on crop production in addition to environmental and genetic variability of crop varieties (Cooper *et al*., 2021; Young *et al*., 2021). At the moment, the most effective management techniques are those that can simultaneously enhance soil biodiversity, plant nutrition, and crop yields (Struik and Kuyper, 2017; Spiegal *et al*., 2018). In the present study, all treatments with beneficial microbes and plant bioactive materials matched agrochemicals in doubling soybean grain yield when compared to the untreated control. This comparable yield suggests that beneficial microbes and plant bioactive materials provided soybean plants with a commensurable amount of nutrients as chemical fertilizers, while additionally enhancing soil biotic processes (Qi *et al*., 2022).

## Conclusion

Soil biotic interactions (soil microbial biomass, total root bacteria and enzyme activities) and soybean grain yields were significantly affected by management practices. All the tested management practices significantly enhanced soybean grain yield when compared to the no input control. The application of beneficial microbes and plant bioactive materials additionally significantly improved soil microbial biomass and total root bacteria when compared to the chemical applications and the no input control. These results highlight the importance of beneficial microbes and plant bioactive materials as sustainable management options to increase soybean grain yield, and integrating them in agro-ecosystems could be a holistic approach that is economically viable, resource-conserving, socio-culturally adaptable, and environmentally friendly.

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