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Microbial Inoculants in Agriculture: A Microbiological Review from A Nigerian Perspective

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ABSTRACT

Chemical compounds are absorbed by most crops from the soil. Several synthetic fertilizers contain acid radicals, such as hydrochloride and sulfuric radicals, thus increasing soil acidity and adversely affecting soil and plant health. Some plants can also absorb highly recalcitrant compounds. Continuous consumption of such crops can lead to systematic disorders in humans. A reliable alternative to the use of chemical inputs is microbial inoculants, which can act as biofertilizers, bioherbicides, biopesticides, and biocontrol agents. Microorganisms are capable of promoting plant growth, and controlling pests, diseases, and weeds. Microbial inoculants are beneficial microorganisms applied either to the soil or the plant to improve productivity and crop health. These natural-based products are widely used to control pests and enhance soil and crop quality, thereby benefiting human health. Microbial inoculants consist of a blend of microorganisms that work with the soil and its inhabitants to improve soil fertility and health, ultimately benefiting human health. They have the ability to minimize the negative impact of chemical inputs, thereby increasing the quantity and quality of farm produce. This review paper summarizes the effects of microbial inoculants on agricultural soil in Nigeria by examining relevant works related to the topic. To achieve this, databases such as Google Scholar, Frontier in Microbiology, African Journals Online (AJOL), Scopus, Web of Science, ScienceDirect, and Directory of Open Access Journals (DOAJ) were explored to identify studies on the effects of microbial inoculants on agricultural soil in Nigeria.

INTRODUCTION

Soil microorganisms can enhance plant growth and safeguard soils from diseases and environmental stresses (Glick, 2012). These microorganisms form partnerships with plants, promoting growth through beneficial traits such as providing nutrients via biological nitrogen fixation (BNF) and phosphate solubilization, as well as reducing stress through the regulation of 1-aminocyclopropane-1-carboxylate deaminase expression and the production of phytohormones and siderophores, among other mechanisms (Alori, 2016). Introducing these helpful microbes into the soil and plants, a process known as inoculation, is a less harmful and more environmentally friendly approach compared to using chemical fertilizers. Microbial inoculation technology is considered a sustainable agricultural practice, leading to reduced production costs. There is a growing trend in the use of symbiotic or free-living nitrogen-fixing bacteria in sustainable agricultural systems (Koki & Takayoshi, 2013). Research conducted by Omokaro *et al.* (2023) in Delta State, Nigeria, focusing on the perspective of smallholder farmers, it was noted that 47.6% of these farmers utilize chemical pesticides such as Gammalin for the control of pests and diseases. Utilizing inoculants is particularly appealing as it significantly decreases the need for chemical fertilizers and pesticides, and there is a rising availability of commercialized inoculants for various crops (Babalola 2010; Babalola & Glick 2012). The use of microbial inoculants has proved to be a promising technology to obtain an increase in food production and a sustainable agricultural system. The effects of microbial inoculants on agricultural soils include the introduction of soil microbes such as bacteria and fungi. However, this paper reviews research on the effects of microbial inoculants in agricultural soils in Nigeria and its impact on plants and soil.

METHODOLOGY

A literature review was carried out to identify the relevant articles published. The earliest research publication concerning the review was found in 2006. Google Scholar, Frontier in Microbiology, African Journals Online (AJOL), Scopus, Web of Science, Science Direct and Directory of Open Access Journals (DOAJ) databases were explored to identify studies on organic amendment effect on soil fertility in Nigeria using the following keywords in English; 'microbial inoculants use in Nigeria', 'effect of microbial inoculants in Nigerian agriculture', 'effect of microbial inoculants in soil and plants in Nigeria. A total of 150 articles were identified in the initial review but 20 articles were selected to be a good match for the review study based on the objective of the study and geographical location. Figure 1 below shows the system search method.

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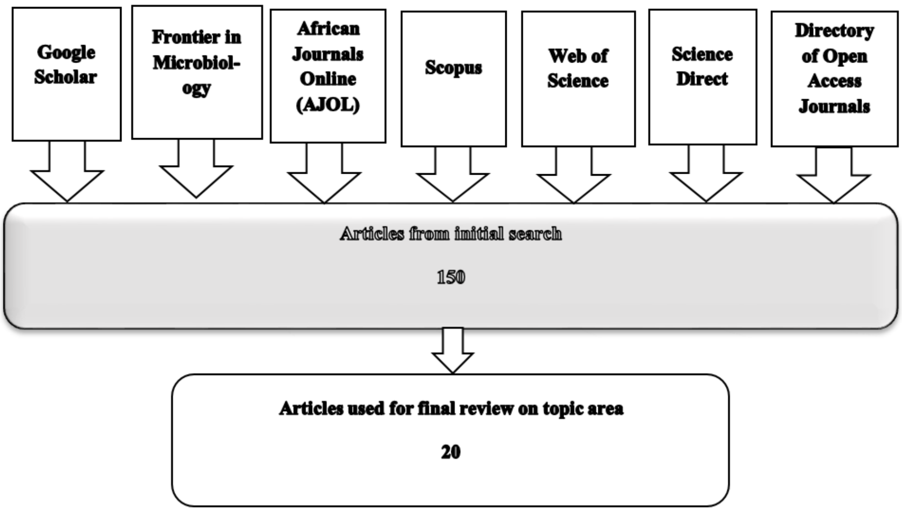

Figure 1: Flow chart showing the methodology of review of literature

DISCUSSION

Microbial Inoculants in Agriculture

Microbial inoculants are formulations containing beneficial microorganisms crucial for maintaining sustainable agriculture in soil ecosystems. They serve as an eco-friendly option, potentially replacing chemical fertilizers and pesticides (Babalola & Glick, 2012). These inoculants consist of active microorganism strains that directly or indirectly enhance microbial activity, improving nutrient mobility in the soil. They can function as phyto-stimulants, bio-fertilizers, or microbial biocontrol agents, offering protection against various pathogens and acting as effective bio-herbicides (Babalola, 2010). Additionally, naturally occurring microbes obtained from the wild and applied to plants can also serve as bio-herbicides (Babalola, 2007; Alori *et al.*, 2017). Given the growing global population and the consequent need to boost agricultural production, maintaining soil fertility is crucial. Biofertilizers, comprising active microbes, present a viable technology to enhance food production without endangering human and environmental health. These biofertilizers encompass organisms that supply or facilitate the availability of different nutrients to plants, including nitrogen fixers, phosphorus solubilizers, potassium solubilizers, sulfur solubilizers, mycorrhiza, and more (Pathak & Kumar, 2016; Alori *et al.*, 2017).

The Effects of Microbial Inoculants in Soil

In the process of seed and soil inoculation, a large number of efficient and viable microbial cells are introduced into the soil to rapidly colonize the host rhizosphere. However, this introduction can significantly disrupt the balance of soil microbial communities (Babalola, 2014). When using microbial inoculants, substantial quantities of microbial cells are introduced into the competitive soil environment. For instance, biocontrol Pseudomonas inoculants that produce 2,4-diacetylphloroglucinol (Phl) are introduced into the rhizosphere community in significant amounts, preventing the proliferation of specific fungal pathogens. Azospirillum spp. produce relatively high levels of indole-3-acetic acid (IAA), which enhance the formation of plant lateral and adventitious roots, improving mineral and nutrient uptake. While introduced microbes may temporarily alter the equilibrium in the rhizosphere community, the bacterial community structure often rebounds due to ecosystem resilience. Compounds like indole-3-acetamide, indole-3-pyruvate, indole-3-acetaldehyde, and 4-chloroindole-3-acetic acid have been found to exhibit auxin activity (Roesti *et al.*, 2006; Olanrewaju *et al.*, 2017).

Biological nitrogen fixation comprises both symbiotic nitrogen fixation and free-living nitrogen-fixing systems. Symbiotic nitrogen-fixing genera include *Rhizobium, Achromobacter, Sinorhizobium, Azoarcus, Mesorhizobium, Frankia, Allorhizobium, Bradyrhizobium, Burkholderia, Azorhizobium*, and *Herbaspirillum* (Babalola, 2010). Phosphorus (P) is a vital element essential for plant growth and development, second only to nitrogen. In soil, P exists in organic and inorganic forms that are not readily available to plants. However, several Plant Growth-Promoting Rhizobacteria (PGPR) have been identified to mobilize poorly available phosphorus through solubilization and mineralization. Examples include *Pseudomonas spp., Agrobacterium spp., Bacillus circulans, Azotobacter spp., Bacillus spp., Burkholderia spp., Enterobacter spp., Erwinia spp., Kushneria spp., Paenibacillus spp., Ralstonia spp., Rhizobium spp., Rhodococcus spp., Serratia spp., Bradyrhizobium spp., Salmonella spp., Sinomonas spp., and Thiobacillus spp.* (Azziz *et al.*, 2012; Alori *et al.*, 2017). Atmospheric nitrogen fixation and mineral solubilization, such as phosphorus (P), are direct mechanisms through which microbial inoculants exert their influence. In indirect growth promotion, microbial inoculants impact plants by inducing systemic resistance (ISR) or systemic acquired resistance (SAR), enhancing disease resistance (Babalola, 2010).

Biotic and abiotic stress such as insect and nematode damage, drought or flood, presence of metals, chemicals (both organic and inorganic), ultraviolet light, extreme temperatures, mechanical wounding as well as fungal and bacterial pathogens triggers increased production of ethylene in plants (Ali *et al.*, 2014). Biocontrol PGPR that produces HCN can also synthesize some cell wall degrading enzymes or antibiotics. HCN can also act as an anti-fungi agent. HCN synthesized by PGPR is usually in small quantity, this ensures that the fungi do not develop resistance to the synthesized antifungal thereby enhancing the effectiveness of antifungal in soil (Kundan *et al.*, 2015; Olanrewaju *et al.*, 2017).

Table 1: Some examples of the use of microbial inoculants in agriculture

Microbial	Location	Result and Findings	References
Rhizobium and *Bradyrhizobium* strains	Ahmadu Bello University, Zaria, Nigeria	Produced more shoot and nodule dry weight	N'cho *et al.*, (2015)
Rhizobacteria inoculant (Nodumax legume inoculant)	Enugu State University of Science and Technology, Nigeria	Increased leaf, stem and root dry weight of Bambara groundnut. Increased number of root nodules, fresh pods of Bambara groundnut and soil total Nitrogen content	Ikenganyia *et al.*, (2017)
Bradyrhizobium	Ahmadu Bello University, Zaria, Nigeria	Increased soil organic carbon, total nitrogen and carbon to nitrogen ratio	Omeke, 2017
Arbuscular mycorrhizae fungi	Federal University of Agriculture, Abeokuta, Ogun State, Nigeria	Increased Arbuscular mycorrhizae root colonization in soybean and maize	Yusif and Hayatu, 2017
Colletotrichum coccodes	Olabisi Onabanjo University, Ogun State	Control of velvetleaf (Abutilon theophrasti)	Babalola, 2007
Azospirillum and Mazospiriflo-2 *(Azospirillum brasilense,* Strain*)*	Shanono, Ibadan	The combined inoculant reduced N accumulation in the shoot biomass of maize	Laditi *et al.*, 2012
Alternaria	Olabisi Onabanjo University, Ogun State	Weed control	Babalola, 2009

The Effects of Microbial Inoculants on Plants

The success of microbial inoculation depends largely on the following: the plant species and cultivar, soil type, soil moisture and temperature conditions, the number of pathogens present in the soil around the plant and how the inoculants were prepared and applied (Babalola *et al.*, 2007). In Nigeria, a study tested the effect of microbial inoculants and foliar fertilizers application on promiscuous soybean (TGx 1448-2E) under smallholder farmers' conditions in the northern Guinea savanna, of Nigeria. Three microbial inoculants; Bradyrhizobium spp. (RACA 6), arbuscular mycorrhizal fungi (Rhizatech) and Trichoderma harzianum (Eco-T) and two foliar fertilizers; Agroleaf high P and Agolyser were used. Grain yield was relatively increased by the application of RACA 6 + TSP, RACA 6 + Agrolyzer and RACA 6 + Rhizatech + Agrolyser compared to the control. The authors suggested that soybean co-inoculation with rhizobial or fungal inoculants and/or foliar fertilizers could lead to improved grain yields (Ncho *et al.*, 2013).

A similar study was conducted for screening of 15 commercial and laboratory rhizobium inoculants in Kadawa (Sudan savanna) and Samaru (northern Guinea savanna) to identify effective and promising products on a promiscuous soybean genotype (TGx 1448-2E) and a Malaysian genotype (SAMSOY-2). More so, an application of three commercial products and seven strains resulted in increased nodulation relative to the control in Kadawa, while two commercial products and six strains increased nodulation, but only two strains resulted in significant increases in biomass and/or grain yield. The authors recommended 1495 MAR, USDA 4675, USDA 110, TSBF 531 and TSBF 560 as effective inoculants to consider for improved grain yield in Samaru (Yusuf *et al.*, 2012). More so, Omeke, (2017) noted that, Integration of inoculated soybean with rhizobium in the maize-based cropping systems in combination with N fertilizer application promotes higher carbon sequestration (stock) and soil N as compared to other treatments combination. A study was conducted in Awka Anambra state, Nigeria to determine the suitability of decomposed rice husk, charcoal and coal to act as carrier materials for cowpea Bradyrhizobia inoculants, using TAL 209, TAL 379 and TAL 173 strains imported from US. The study showed decomposed rice husk as better carrier materials. A follow up pot experiment also confirmed the ability of Bradyrhizobia in decomposed rice husk to nodulate, increase shoot dry matter and total N in cowpea in different soils relative to uninoculated controls (Okereke and Okeh, 2007). Inoculation trials were also conducted on Eutric Cambisols (EC) and Rhodic Nitisols (RN) soils in a greenhouse study. Soybean (TGx 1448-2E), cowpea (IT90K-277-2) and groundnut (SAMNUT 21) were used as test crops along with rhizobia inoculants (MAR 1495, TSBF Mixture, Legumefix, HiStick and IRj 2180A) to determine their response to soil type and ability to form symbiotic relationship with the crops. Rhizobia strains MAR 1495 and TSBF mixture showed similar ability to improve the productivity of soybean and groundnut and thus recommended for use as common inoculants for the two crops (Aliyu *et al.*, 2013).

Furthermore, the influence of rhizobia inoculation on N-fixation by cowpea (Vigna unguiculata (L.) Walp.), groundnut (Arachis hypogaea L.) and bambara groundnut (Vigna subterranea L.Verdc.) was evaluated under field condition in Maiduguri, Sudano-Sahelian zone of Nigeria. Strains isolated from the same crops the previous year were used to inoculate them the next year. The results showed rhizobia inoculation to increase the amount of N- fixed by 46% over the control. Cowpea fixed 42.68 kg N ha^{-1} while groundnut and bambara groundnut fixed 27.19 and 32.53 kg N ha^{-1}, respectively. This indicates a higher potential of cowpea to alleviate soil nitrogen deficiency over the other legumes, particularly where the indigenous rhizobia nodulating the crops are inadequate (Yakubu *et al.*, 2010).

CONCLUSION

In Nigeria, the use of chemicals in agriculture can be avoided and thus they can be removed from human diets and minimize the reduction of environmental hazards. Pest and weed control can be achieved by employing microbial inoculants as biocontrol agents and bio-herbicides. Harnessing natural resources including beneficiary microorganisms is one of the most effective approaches to improving farm productivity and food quality in a sustainable way. Microbial inoculant as part of agricultural practices will ensure healthy food security for the future population. Several findings of microbial inoculants have been shown to improve soil properties, crops growth, biotic and abiotic stress and nutrient intake and further improve health living between microorganisms and plant in the root region. However, these findings are not restricted to Nigeria alone and have necessitated the need to adopt microbial inoculants in other regions of the world. However, with the bulk of farmers in Nigeria being unlettered and majority uneducated, it could be challenging to change their mindset and convince them of probable alternatives to the use of inoculants as a means of bio-fertilizers.

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