Potentials of Microbial Inoculants in Soil Productivity: An Outlook on African Legumes

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Abstract

Nutrient availability is one of the major limiting factors affecting legume production in Africa. With the limited arable land resources, meeting the dietary requirement of the ever-increasing world population becomes a serious challenge. The most frequently deficient nutrient on crop fields is nitrogen (N). Inconvenient increase in prices of chemical nitrogen fertilizers together with the environmental problems associated with their excessive use calls for alternative low-cost and ecologically friendly soil-plant fertilization technologies. Soil microorganisms play significant roles in nutrient mineralization and supply to plant hence promoting plant growth. Soil microbes suppress soilborne plant diseases and destroy environmentally hazardous compounds in soil. Microbial inoculants are agricultural amendments that use microorganisms such as rhizobia and endophytes to promote legume growth. These microbes form symbiotic relationships with the target leguminous plant, and both parts benefit. The structure and function of the plant microbiome are major determinants of plant health and productivity. Microbial inoculants are the potential tools for sustainable agriculture.

Keywords

Microbiome • Nitrogen fixation • Soil fertility • Soil health • Soil quality

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3.1 Introduction

The over-reliance on conventional agricultural systems, which depend highly on non-sustainable energy inputs and intensive use of herbicides, fertilizers and pesticides, does not hold the answer to obtaining higher yields from food crops grown in Africa. In order to meet the ever-rising demand for sustainable land use, increased feed and biofuel production as alternative to nonrenewable fossil fuels, there has been an expanding demand to improve the soil quality through the production and utilization of nitrogen-rich composts. The residual effect of these non-sustainable practices of may have an adverse effect on the community as a whole. Legumes are fit and often used for the building up of a friendly and advantageous association with soil microorganisms known as rhizobia that create pull knobs for lessening of climatic dinitrogen to effectively assimilable structures for use by the host plants. An extraordinary level of organism group's specificity exists in rhizobia-legume associations, emerging from a signal interchange in the two partners. The root nodule initiation, on the other hand, requires a set of vastly coordinated events at the root epidermal and cortical cells; there has been an expanding reliance on concentrated agribusiness. These unsustainable practices may prompt to the decay of soil quality and require the generation of nitrogen manures to the detriment of nonrenewable fossil powers. Besides the growing cost of improvement, the excessive usage of manures is in addition responsible for the damage to various organic frameworks (Hawkesford 2011). Hence, the use of microbial inoculants has proved to be a promising technology to obtain an increase food production and a sustainable agricultural system. Soil microorganisms are capable of enhancing plant growth and protect soils from disease and abiotic stresses (Glick 2012). Microorganisms establish associations with plants and promote plant growth by means of several beneficial characteristics such as nutrient availability from genetic processes of biological N fixation (BNF) and phosphate solubilization and stress alleviation through 1-aminocyclopropane-1-carboxylate deaminase expression modulation and the production of phytohormones and siderophores, among several others (Alori 2016).

The introduction of beneficial microbes to soil and plant (inoculation) is less aggressive and causes less damage to the environment compared to chemical fertilization. Microbial inoculation technology is therefore a sustainable agronomic practice that reduces production costs. There are increasing applications of symbiotic or free-living N-fixing bacteria in sustainable agricultural systems (Koki and Takayoshi 2013). The application of inoculants is seen as being very attractive since it would substantially reduce the use of chemical fertilizers and pesticides, and there are now an increasing number of inoculants being commercialized for various crops (Babalola 2010; Babalola and Glick 2012a, b; Berg 2009). Microbial inoculants comprise three major groups of soil microbes which are symbiotic nitrogen-fixing rhizobia, plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF).

Rhizobia species are well investigated because of their symbiotic relationship with leguminous plants and their agronomical application as inoculants in the cultivation of economic crops (Ajilogba and Babalola 2013; Ajilogba et al. 2013; Torres et al. 2012). The soybean-*Bradyrhizobium* association is a good example of the efficiency of BNF, while *B. elkanii* and *B. japonicum* are species that are commonly used to inoculate this leguminous plant. In this system, the BNF is so efficient that attempts to increase grain yields by adding nitrogenous fertilizers are not successful in plants that had been effectively inoculated with the recommended *Bradyrhizobium* strains (Souza et al. 2015).

Legumes have served man as source of food, feed, fuel wood and fertility from the very early times, hence, described as 'soil improvers' (Ajilogba and Babalola 2013; GRDC 2013). The unique ability of legumes to fix atmospheric N through symbiotic association with root-nodule bacteria had been used to improve the yields of legumes in sub-Saharan Africa (Abaidoo et al. 2013). Moreover, most of the soils used for legume production in Africa are poor in nutrient status, especially total N, organic carbon and available phosphorus and, therefore, relatively unproductive (Laditi et al. 2012; Machido et al. 2011). Leaching, denitrification, volatilization, nutrient mining and depletion by crop and crop residue removal for alternative uses have all contributed to the further worsening of the low fertility situation (Yakubu et al. 2010). Hence, the replenishment of depleted soil nutrients, especially N, depends largely on the addition of inorganic fertilizers, which rank first among the external inputs that are required to maximize agriculture outputs, but in turn contributes substantially to environmental pollution (Alori et al. 2012). On the other hand, most farmers cannot afford inorganic fertilizers due to their high cost and non-availability on time in the region (Yakubu et al. 2010) resulting in low to suboptimal use (Kutu and Asiwe 2010; Kutu and Diko 2011) that neither mitigate the nutrient mining problem nor guarantee soil fertility restoration for optimum crop growth and productivity. Consequently, this has led to a renewed farmers' interest on BNF, which provides a continuous in situ supply of N for plant growth, adds organic matter to the soil and is economically viable (Yakubu et al. 2010). Most importantly, inoculation of legume crop is recommended when the field has not been cropped with the host plant for the past 3–5 years or when it has never been planted to the host (Yakubu et al. 2010). Moreover, inoculation of legume can increase rhizobia populations in fields where environmental conditions for the bacteria's long-term survival are not favourable. For instance, the rhizobia population of a field with pH below 6.0, periodically flooded conditions or extremely sandy soils can be greatly improved by microbial inoculation for maximum legume production (Machido et al. 2011).

The success of a legume grain crop is dependent on its capacity to form effective nitrogen-fixing symbioses with root-nodule bacteria. Many soils, however, do not have adequate amount of native rhizobia in terms of number, quality or effectiveness to enhance BNF. These situations call for the provision of external source of rhizobia through inoculation that to enable effective legume nodulation and N_2-fixation. Three of such situations were identified that legumes generally need inoculation: (1) where compatible rhizobia are absent, (2) where the population of compatible rhizobia is small and (3) where the indigenous rhizobia are ineffective or less effective in N_2-fixation with the intended legume than selected inoculant strains (Vanlauwe and Giller 2006).

Ronner et al. (2016) discussed the history of rhizobia inoculants used for grain legume improvement in Nigeria. However, information on the exploration of the potential of microbial inoculants in the production of African legume is limited. This review therefore detailed the legume microbiome in soil. It provides an overview of the interaction of endophytic microbes with legumes, legume microbial inoculants for organic farming, legume microbial inoculants for soil fertility and legume microbial inoculants for soil health improvement. Legumes commonly planted in African were well expatiated.

3.2 Legumes Microbiome in Soil

The rhizosphere is the area of soil encompassing the root which is influenced by it. The importance of the rhizosphere emerges from the discharge of natural material from the root and the consequent impact of expanded microbial action on nutrient cycling and plant development. In the rhizosphere, the amounts and the classes of substrates are not quite the same as those in the mass soil, and this prompts to colonization by various populaces of microbes including bacteria, fungi, protozoa and nematodes. Other physicochemical elements which can be distinctive in this area are acidity, humidity and nutrient status, electrical conductivity and redox potential. The relationship among organisms and roots can be helpful (water take-up, soil stability, growth advancement, N_2-fixation, biocontrol, antibiosis, beneficial interaction), detrimental (disease, phytotoxicity) or unbiased (nutrient flux, free catalyst discharge, connection, allelopathy, rivalry)—these impacts frequently rely on soil conditions and in this manner should be considered as factors (Chaparro et al. 2012). Relationships that are helpful to farming integrate mycorrhizae, legume nodulation and formation of antimicrobial complexes that restrain the development of pathogens. Clearly, balancing the effect of the beneficial elements of the rhizosphere will assist in manipulation of the rhizosphere.

3.3 Rhizobia

Rhizobia are free-living facultative saprophytic organism dwelling in the root knobs of the most legumes. They exist in the rhizoplane, rhizosphere as well as in the soil apart from the rhizosphere in small quantity. Rhizobia are more prevalent in the rhizosphere of the legumes as a result of the plant root exudate. Diversity of the host legumes is significantly found in connection with various gene pools of indigenous rhizobia. The formation of nodules by rhizobia in relation to legumes is highly specific. These rhizobia are described by their capacity to deliver hypertrophies (swellings) or knobs on the stems or roots of most however not all legumes (Mus et al. 2016). Not all the legumes form nodules and those that form only do so with specific rhizobia. On the other hand, some of the rhizobia are promiscuous, having the capability of nodulating more than one legumes (Ampomah et al. 2008). These rhizobia are unique among the soil microbes due to the N-fixing capability whenever in mutualistic relationship with compatible legumes. The physiological versatility of these rhizobia enables their adaptation to the complex and competitive soil

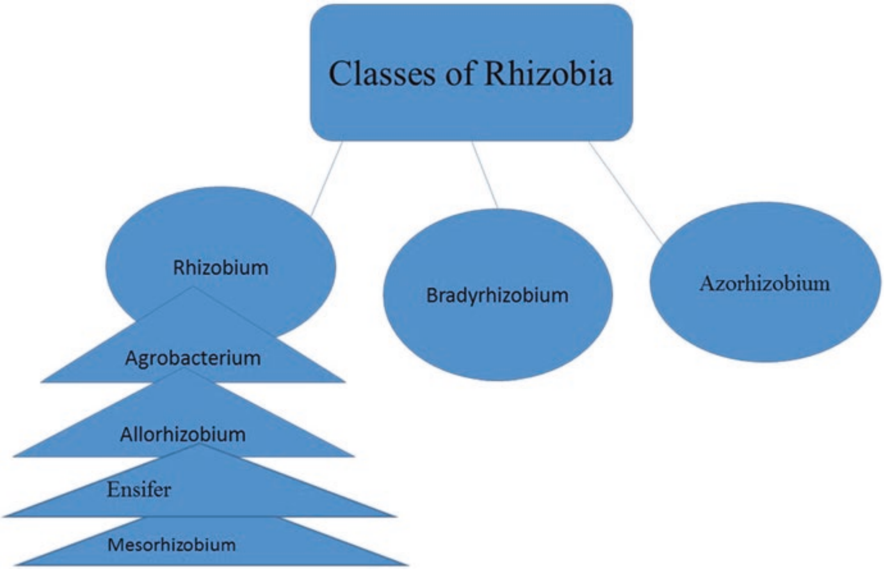

Fig. 3.1 Classes of rhizobia

environment. Rhizobia convert atmospheric dinitrogen (N_2) into absorbable ammonia for the improvement of plant growth and productivity. The process is eco-friendly and without any exogenous release to the soil.

The rhizobia nodulation ability and N-fixing ability with a wide range of legumes also enhance their persistence in the soil. The taxonomy of these rhizobia is in the state of flux (Shamseldin et al. 2017). Presently, there are three groups as illustrated in Fig. 3.1. The difficulty in the classification of rhizobia is due to the nodulation genes borne on the plasmid or found on the chromosomal symbiotic islands that move between the soil microorganisms, which weaken the infection based on taxonomic analysis (Shamseldin et al. 2017).

There are two major genera of rhizobia, which include the *Rhizobium* species (spp.) that are associated with legumes and the *Bradyrhizobium* species which are in the other hand associated with soybean and cowpea. When grown on a special growth medium called yeast-mannitol agar (YMA), *Rhizobium* spp. produce an acid growth reaction, while the *Bradyrhizobium* spp. produce alkaline reaction. When rhizobia live on organic material in the soil, without legume partner, they are called saprophytes. Many factors like environmental and soil conditions (soil moisture, pH and temperature), cropping history and vegetation affect the number of rhizobia in the soil. Rhizobia bacteria require the availability of molybdenum (Mo), a soil element for effective nitrogen fixation. Although Mo is abundantly present in soils, its availability is greatly influenced by soil pH and considered most adequate at pH values of between 6.5 and 7.0.

Rhizobia are reported to influence crop growth, yield, and nutrient uptake by different mechanisms (Dudeja and Giri 2014). They fix N, help in promoting free-living N-fixing bacteria, increase the supply of other nutrients such as phosphorus (P) and iron (Fe), produce plant hormones, enhance other beneficial bacteria or fungi, control bacterial and fungal diseases and help in controlling insect pests (Dudeja and Giri 2014). This symbiosis can therefore help reduce the requirements for the addition of nitrogenous fertilizer during the growth of leguminous crops. Inoculation with rhizobia induces the proliferation of plant growth-promoting microorganisms (PGPMs) like *Bacillus*, *Rahnella*, *Pseudomonas*, *Mesorhizobium*, *Streptomyces*, *Sinorhizobium* and *Azospirillum*, among others. Inoculation with *rhizobia* also causes a perturbation of the microbial community. Legumes include some of the most important commercial crops under cultivation, such as soybean (*Glycine max*), pea (*Pisum sativum*) and common bean (*Phaseolus vulgaris* L.).

3.4 Legume-Nodulating Bacteria

Apart from rhizobia, there are other bacteria that possess ability to nodulate leguminous plants. Presently, these belong to three main groups belonging to *Alphaproteobacteria*, *Betaproteobacteria* and *Gammaproteobacteria* (Shamseldin et al. 2017). The family *Rhizobiaceae*, *Phyllobacteriaceae*, *Bradyrhizobiaceae*, *Hyphomicrobiaceae* and *Brucellaceae* belong to the largest class (*Alphaproteobacteria*), while the *Betaproteobacteria* formed the second of the only one family, the *Burkholderiales*, which contains only two genera (Fig. 3.2). There are 98 legume-nodulating bacteria that are attributed to 18 main genera with 238

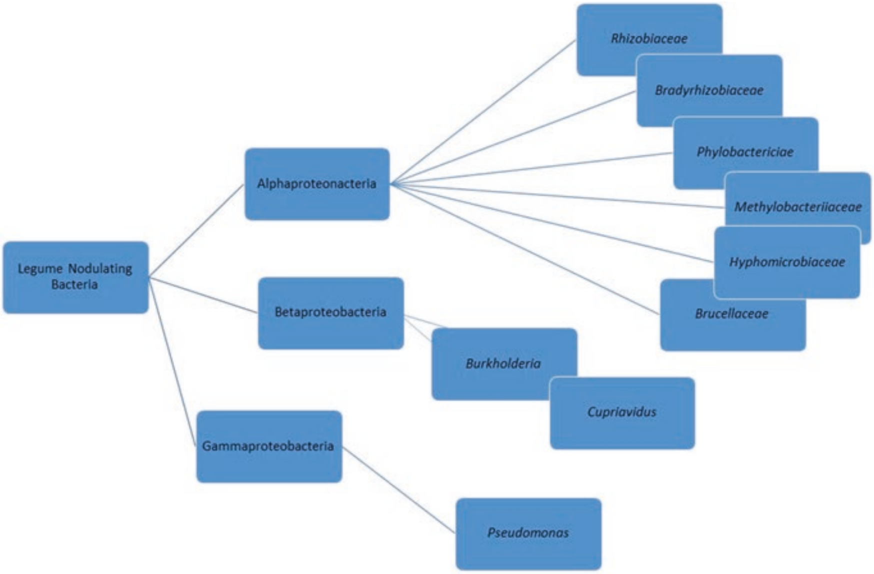

Fig. 3.2 Legume nodulating bacteria

species, out of which *Rhizobium* and *Bradyrhizobium* are the two largest genera (Berrada and Fikri-Benbrahim 2014).

3.5 Interactions of Endophytic Microbes with Legumes

Endophytic microbes are microbes that colonize the inside of plant tissues (legume and nonlegume) without causing any harm to the host plant. Endophytes have been reported in about 300, 000 species of plants (Dudeja and Giri 2014) and have potential use in sustainable agriculture. Endophytic microbes play major role in agricultural environment and produce many natural products that could be used in agriculture, industry and medicine (Ruby and Raghunath 2011). Endophytic microbes may be more important than rhizospheric microbes in promoting plant growth because they escape competition with rhizosphere microorganisms and achieve close contact with the plant tissues. Colonization of host plant by endophytes depends on seasonal changes, soil hydric stress and plant defence response among others (Dudeja and Giri 2014). About 200 genera of culturable and nonculturable bacteria belonging to 16 phyla have been reported as endophytes that include *Acidobacteria*, *Cyanobacteria*, *Firmicutes*, *Nitrospira*, *Actinobacteria*, *Bacteroidetes*, *Deinococcus-Thermus*, *Fusobacteria*, *Proteobacteria*, *Spirochaetes*, *Planctomycetes*, *Verrucomicrobia*, *Chlorobi*, *Gemmatimonadetes*, *Aquificae* and *Chloroflexi* (Sessitsch et al. 2012). However, the genera *Gluconobacter*, *Pseudomonas*, *Stenotrophomonas*, *Serratia*, *Bacillus*, *Enterobacter* and *Burkholderia* belong to the phylum *Proteobacteria*, while *Actinobacteria* and *Firmicutes* are the most predominant and studied endophytes (Babalola 2010; Kumar et al. 2013; Ryan et al. 2008; Taghavi et al. 2009; Taghavi et al. 2010; Weilharter et al. 2011). The nodules in the roots of legumes particularly pea (*Pisum sativum*), lucerne (*Medicago sativa*) and chickpea (*Cicer arietinum*) and nonlegumes such as oat (*Avena sativa*), rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), maize (*Zea may*), carrot (*Daucus carota* L.), banana, coffee, citrus plant and wheat (*Triticum aestivum*) contain a verse load of endophytic bacteria (Dudeja and Giri 2014; Saini et al. 2015). Dudeja et al. (2012) and Dudeja and Giri (2014) reported the isolation of endophytic bacteria from the nodules and roots of many legumes, pea, cowpea, alfalfa, chickpea, *Conzattia*, mung bean, fenugreek, *Acacia*, *Kennedia*, soybean, *Psoralea*, *Mimosa*, *Oxytropis*, clover, *Scorpiurus*, *Vicia*, *Sesbania*, *Lotus*, *Hedysarum*, *Ornithopus*, bean, *Onobrychis*, *L. tetragonolobus*, *Leucaena*, peanut, *Argyrolobium*, *Melilotus* and *Medicago*. Similarly, endophytic bacteria were isolated from the nodules of *Sophora alopecuroides* (Zhao et al. 2013). The array of endophytic bacteria that have been reportedly isolated from legume tissues include *Inquilinus*, *Rhodopseudomonas*, *Paracoccus*, *Ornithinicoccus*, *Serratia*, *Pedobacter*, *Bacillus*, *Starkeya*, *Staphylococcus*, nose *Mycobacterium*, *Brevibacillus*, *Lysinibacillus*, *Pseudomonas*, *Nocardia*, *Sphingomonas*, *Dyella*, *Phyllobacterium*, *Aerococcus*, *Ochrobactrum*, *Agromyces*, *Stenotrophomonas*, *Methylobacterium*, *Actinobacteria*, *Paenibacillus* and *Streptomyces* among others. A single host plant may comprise several genera and species of endophytes (Dudeja and Giri 2014). Wang et al. (2013) and Palaniappan et al. (2010) isolated 72 and 39 endophytic bacteria from *Arachis hypogea* and *Lespedeza* sp., respectively.

Endophytes improve plant growth attributes with respect to increased biomass, germination rates, hydraulic activity, nitrogen content, root and shoot length, chlorophyll content, yield tolerance to biotic (pest and pathogen) and abiotic (such as salinity, acidity, flood and drought) stresses and protein content (Khan et al. 2017; Sánchez-Romera et al. 2016). The impact of endophytes on the host plant can be through direct biochemical activities like BNF, phosphate solubilization, phytohormone production and inhibition of ethylene biosynthesis in response to abiotic and biotic stresses (induce systemic tolerance) or indirect such as inducing resistance to pathogen (Bhattacharyya and Jha 2012). More also, endophytic bacteria produce secondary metabolites that affect the plant directly or indirectly. These metabolites include ammonia, organic acids and enzymes like pectinases and celluloses (Dudeja and Giri 2014). Listed in Table 3.1 are examples of some legume microbial inoculants and their beneficial properties.

3.6 Legume Microbial Inoculants for Organic Farming

Certain microbial inoculants such as nitrogen-fixing rhizobia and mycorrhizae can improve soil nutrients and reduce disease infestation on legume plant under organic farming (Bhardwaj et al. 2014). When using purchased commercial inoculant in organic production of grains legume, forage legume or cover crops, it is important to avoid inoculants produced from genetically modified organisms, recombinant DNA technology, sewage sludge or ionizing radiation (Mapelli et al. 2012). The reason for using microbial inoculants in organic farming is as a result of the fact that most rhizobia species are organotrophs, that is, they get the derived energy from organic matter (Mendes et al. 2013). There is insufficient accessibility and availability of degradable organic compounds in many soils, while carbon accessibility is the most widely known constraining component for the growth of soil bacteria (Rousk and Bååth 2007). The nutritive cations of the soil minerals are released through the activities of these bacteria for their own sustenance as well as for plant nourishment. The mineral weathering microorganisms have been identified from different environments, especially from rhizosphere and ectomycorrhizosphere (Collignon et al. 2011), and often can add to the growth of plant in nutrient-poor soils (Leveau et al. 2010; Mapelli et al. 2012).

3.7 Legume Microbial Inoculants for Nitrogen Fixation

In soils with low mineral N content, nitrogen-fixing microorganisms provide ammonium into the legume biomass that allows for faster growth. The symbiosis is initiated through the legume root infection by the rhizobia and the formation of root nodules where biological N fixation occurs through the action of a bacterial enzyme,

Table 3.1 Examples of some legume microbial inoculants and their beneficiary properties

Legume crop	Microbial inoculants	Beneficial properties	References
Soybean	*Rhizobium* sp., *Bradyrhizobium* sp., *Trichoderma harzianum*	Production of growth hormones and biocontrol	N'cho et al. (2015)
Pea	*Rahnella* sp.	P-solubilization, production of 1-aminocyclopropane-1-carboxylate (Bilia et al. 2014) deaminase	Vyas et al. (2010)
Cowpea	*Bradyrhizobium* spp.	Production of growth-stimulating hormones	Morel et al. (2012)
Chickpea	Arbuscular Mycorrhiza	Protective response under restrictive condition	Farzaneh et al. (2009)
Cowpea	*Scutellospora reticulata* and *Glomus pansihalos*	Bio-remediation	Alori and Fawole (2012)
Pea	*Pseudomonas* sp.	Production of growth-stimulating hormones	Germaine et al. (2009)
Faba bean	*Rhizobium leguminosarum* bv. viciae and arbuscular mycorrhizal fungi	Protective response under restrictive environmental condition	Abd-Alla et al. (2014)
Chickpea	*Bacillus subtilis*, *Bacillus amyloliquefaciens*, and *Mesorhizobium*	Production of growth	Saini et al. (2015)
Pigeon pea	*Bacillus* sp. and *Rhizobium* spp.	Production of growth	Rajendran et al. (2008)
Chickpea	*Pseudomonas* sp. and *Mesorhizobium* sp.	Production of indole acetic acid (IAA)	Malik and Sindhu (2011)
Pea, Lentin	*Bacillus thuringeinsis*-KR1 and *Rhizobium leguminosarum*	Growth and nodulation	Mishra et al. (2009)
Pigeon pea	Rhizobacteria and *Rhizobium*	Nodulation and nitrogen fixation	Tilak et al. (2006)
Common bean	*Rhizobium* and *Pseudomonas*	Growth and yield	Sáncheza et al. (2014)
Lentil	*Rhizobium leguminosarum*	Growth nodulation and yield	Muhammad et al. (2012)
Common bean	*Rhizobium-Azospirillum*	N fixation	Remans et al. (2008)

called 'nitrogenase' (Masson-Boivin et al. 2009). Inoculating the legume plant with efficient nitrogen-fixing microorganisms improves its potential to biologically fix atmospheric N. These kinds of microbial inoculants, also known as soil inoculants, are agricultural amendments that use microorganisms known as rhizobia to promote legume growth. These bacteria form symbiotic relationships with the target leguminous plant, and both parts benefit. Inoculation of legumes with microbial inoculants results in a tremendous increase in number and mass of nodules, nitrogenase activity, leghaemoglobin content of nodule and dry mass of root and shoot (Abd-Alla et al. 2014). Nitrogen fixation is very efficient in satisfying the high N requirements of legumes because the conversion of gaseous N_2 to NH_3 takes place inside the plant. All of the fixed N is readily available and in the form required for combination with carbohydrates to produce the amino acids used for the manufacture of protein. Furthermore, since N fixation in the root nodules is directly dependent on the translocation of carbohydrates from the leaves, the rate of fixation is fully 'synchronized' with the rate of plant growth (Zhang et al. 2014).

In addition, to reinstate N availability of poor soil, it depends solely on the number of successful strains of the *Rhizobium* close to the rhizosphere to accelerate N fixation. Every legume requires a particular type of *Rhizobium* for effective nodulations. Although numerous legumes might be modulated by diverse strains of rhizobia, growth and N availability could only be possible by specific strains rhizobia for specific legumes (Mahdi et al. 2010). It is consequently critical to coordinate microsymbionts wisely for most extreme N fixation. A strain of rhizobia that nodulates and fixes a lot of N in one legume variety may likewise do in relationship to certain other leguminous species. This must, however, be confirmed by testing. Leguminous plants that show this propensity to react comparatively to specific strains of rhizobia are considered 'effectiveness' classes. Hence the amount of N fixed varies according to the legume species and variety. More also, alkalinity significantly inhibited nodulation and N fixation in legumes inoculated with microbial inoculant (Abd-Alla et al. 2014). The potential for N fixation is directly related to rhizobia survival, the extent of effective nodulation and plant growth factors. Any adverse soil condition or environmental stress that affects plant growth is likely to slow down the N fixation process. Nitrogen fixation is also affected by the level of available N in the soil. High soil N levels reduce N fixation because legumes will preferentially use most of the available soil N before they begin to fix atmospheric N. Nodule formation will be progressively inhibited as soil nitrate-N levels rise above about 39.2 kg ha^{-1}, and little fixation will occur with soil nitrate-N levels above 61.6 kg ha^{-1} (Abd-Alla et al. 2014).

3.8 Legume Microbial Inoculants for Soil Fertility and Increased Crop Productivity

The sustainable productivity of an agroecosystem largely depends on the ability of the soil to supply essential nutrients to the growing plants (Abd-Alla et al. 2014). Recently, there is an emerging demand to decrease the dependence on chemical fertilizers that has become a major input in crop production worldwide and ultimately increase the sustainability of agriculture. Today, only 30–50% of applied N fertilizer and 10–45% of P fertilizer are taken up by crops (Singh et al. 2016). Hence there is a need to explore alternative sources which are environment friendly and cost effective. Microbial inoculant, an alternative source of N and P fertilizer, in legume symbiosis, is a promising technology (Youseif et al. 2017). The symbiosis between legumes and rhizobia is one of the important ecological mutualisms. Legumes vary in their potential to improve soil fertility. In this wises legumes could be ranked as follows: green manure crops > forage crops > low harvest index grain legumes > high harvest index grain legumes (Abd-Alla et al. 2014). Hence, legumes microbial inoculation has become a significant practice in the development of sustainable soil management system.

Members from the rhizosphere microbiome can altogether impact on the nutrient status of plants. Commonly known are the nitrogen-fixing rhizobia and the mycorrhizal fungi that enhance P take-up (Miransari 2011). The significance of symbionts such as mycorrhizal fungi for the translocation of nutrients and minerals from soil to the plant (Adeleke et al. 2012; Gianinazzi et al. 2010; Wallander et al. 2013), the production of stable soil aggregates and the destruction of soil borne plant pathogens (Pozo and Azcón-Aguilar 2007) is well reported (Salvioli and Bonfante 2013). Apart from *Rhizobium* and *Bradyrhizobium*, other N-fixing living bacteria like *Cyanobacteria*, *Proteobacteria*, *Actinobacteria,* and *Bacilli* have been recognized in the rhizosphere (Gaby and Buckley 2011). For instance, exploration of the cowpea rhizosphere showed a high genetic difference of mutualistic rhizobia species in western Amazon (Guimarães et al. 2012). Results of glasshouse trials and 16S rRNA gene sequencing revealed that *Bradyrhizobium*, *Rhizobium*, *Burkholderia* and *Achromobacter* species are highly effective for nodulation of cowpea (Guimarães et al. 2012). Notwithstanding the broad research on N fixation by rhizobia, the exchange of nitrogen is related to the amounts of comparable legume. The legume-specific beneficial interaction to other agriculturally critical plant species has not been revealed. Geurts et al. (2012) revealed that understanding the central contrast between the apparently comparative cell reactions incited by *Rhizobium* and mycorrhizal organisms will be important to accomplish this ‘old dream’. Rhizosphere microorganisms can likewise encourage the take-up of particular trace elements, like iron which is plentiful in soil under acidic to basic conditions just like Cu, Mn and Zn. and exists fundamentally in the insoluble ferric oxide form that is not accessible for the growth of microorganism. Owing to the shortage of accessible iron in numerous microbial environments and higher concentration of toxic free iron, bacteria utilize diverse mechanisms in order to manage the intracellular iron concentration through the production of siderophores (Hider and Kong 2010). On the host side, plants react to iron limitation by either expanding the dissolvability of inorganic iron in the rhizosphere or by discharging phytosiderophores that are in this manner transported once more into the root tissue by a particular take-up system (Walker and Connolly 2008).

3.9 Legume Microbial Inoculants for Soil Health Improvement

A healthy soil is one that adequately performs its functions, which are important to humans, such as providing a medium for plant growth biological activity, regulating the partitioning of water flow and storage in the environment and serving as an environmental buffer in the formation and destruction of environmentally hazardous compounds. The ability of legumes and associated microbes to degrade pollutants permits plants to grow as natural vegetation at contaminated sites. Legume microbial inoculants degrade pollutant compounds, aid rhizoremediation, solubilize P, fix atmospheric N and secrete siderophores (Aziz et al. 2016). One of the ways to promote soil health is to inoculate legumes with rhizobial bacteria that form symbiotic relationship with the host plant. Seeds could also be inoculated with treatments comprising of beneficial microorganisms that protect seedlings from soil borne diseases (Trabelsi and Mhamdi 2013).

The microbial inoculants in the rhizosphere give the forefront resistance to plant roots against assault by soil borne pathogens. Different individuals from the rhizosphere microbiome can alienate soil borne pathogens before and during primary infection and secondary spread on and in root tissue. The major means of wiping off plant pathogen by the rhizosphere microorganisms are antibiosis (Raaijmakers and Mazzola 2012), parasitism and rivalry for trace element, nutrients and microsites (Druzhinina et al. 2011), impedance with majority detecting influencing harmfulness and induced systemic resistance (Berendsen et al. 2012; Pieterse et al. 2012). Most, if not all, rhizobacteria produce metabolites that restrain the growth of contending microorganisms. Likewise, rhizosphere fungi are productive makers of antitoxin metabolites (Brakhage and Schroeckh 2011). Among the metabolites produced by the rhizosphere microorganisms are volatile organic compounds (VOCs) that balance up the growth of plant as well as control the dialogues among microbes and plants (Bailly and Weisskopf 2012; Effmert et al. 2012). In spite of the fact that VOCs are smaller than the aggregate number of metabolites released by fungi and bacteria, they are unique in the establishment of crosstalk with the rhizosphere and in soil biological systems. VOCs are little particles (<300 Da) with high vapour weights ready to diffuse through the water-and gas-filled pores in soil (Insam and Seewald 2010). Different bacterial species including *Stenotrophomonas maltophilia*, *Serratia plymuthica*, *Pseudomonas trivialis*, *P. fluorescens*, *B. subtilis* and *Burkholderia cepacia* release VOCs that hinder mycelial development of parasitic plant pathogens (Effmert et al. 2012). These VOCs are controlled by the root exudates. Late work demonstrated that the range of volatiles discharged by rhizobacteria can be impacted by the accessible pool of root exudates. For instance, volatiles formed in soil corrected with simulated root exudates without amino acids had solid antibacterial impacts yet mellow antifungal impacts, though volatiles delivered from root exudates supplemented with amino acids had solid antifungal impacts. At last, VOCs can likewise induce systemic resistance in plants and advance plant development (Bailly and Weisskopf 2012). Members from the rhizosphere microbiome can likewise influence the plant resistant system (Berendsen et al. 2012; Pieterse et al. 2012). The systemic resistance reaction prompted in plants by valuable rhizobacteria is by and large, managed by the phytohormones jasmonic corrosive (JA) and ethylene (ET) (Zamioudis and Pieterse 2012). Nonetheless, some bacterial strains do not instigate systemic resistance by means of the JA/ET pathway however through the salicylic corrosive (SA) pathway (Pieterse et al. 2012).

3.10 Legume Microbial Inoculants for Soil Quality Enhancement/Maintenance

A range of soil factors are known to build nutrient accessibility and plant production. The most significant might be the entities including the soil microbiome of the rhizosphere, which is the soil encompassing the underlying root of plants where complex relations transpire between the roots, soil, and microorganisms. Root exudates serve as substrates and signalling molecules for microbes making an unpredictable and joined relationship among plants and the microbiome. The larger group of soil microorganisms mainly the endophytes, symbionts, pathogens and plant growth-promoting rhizobacteria have greater impact on the soil microbiome. Each microbe teams up with the general soil microbiome to impact on plant well-being and crop efficiency. Carvalhais et al. (2013) and Panke-Buisse et al. (2015) revealed in their extensive studies that plants can shape the soil microbiome through the root exudates discharge. The molecular communication changes according to the plant improvement level, closeness to neighbouring species, management methods, and many other factors (Chaparro et al. 2012).

3.11 African Legume Crops

Fabaceae or Leguminosae belong to legume commonly referred to as Fabaceae, which is one of the biggest and most financially key plant families. Legumes are the third-biggest group of angiosperms, comprising ca. 730 genera and ca. 19,400 species (Velázquez et al. 2010). In contrast with Asteraceae (23,000 spp.), Orchidaceae (22,000 spp.), and other substantial plant families, Fabaceae are target group of worldwide plant diversity for various reasons. Fabaceae incorporates numerous valuable plants, for example, crops, legumes, timber, ornamentals and therapeutic plants (Saslis-Lagoudakis et al. 2011). Habitat difference of Fabaceae is amazingly high; legumes arise from the tropics to cold zones, from the seashore to high-altitude habitats and in rain timberlands, mangroves, peat-overwhelm woodlands, occasional backwoods, savannahs and deserts.

Furthermore, Fabaceae demonstrate high differing qualities in three fundamental tropical vegetation sorts including the tropical rain timberlands, dry backwoods and woody savannahs (Särkinen et al. 2011; Simon et al. 2011). However, the other families mentioned above have similar diversity, if by any means, in only one of these vegetation categories. Plants of Fabaceae also harbour numerous explicit herbivorous creepy crawlies and sustain specific food webs. Many legume species are in mutual relationship with knob-shaping microscopic organisms with N fixation capacity and all things considered bolster imperative environment capacities (Sprent et al. 2009). There is a significant collection of confirmation from morphological and subatomic phylogenetic reviews to bolster the Fabaceae as a monophyletic family (Bruneau et al. 2008). It customarily has been partitioned into three subfamilies Caesalpinioideae, Mimosoideae and Papilionoideae, on the premise of morphological contrasts, especially in botanical characters (Peix et al. 2015).

On the premise of molecular phylogenetic reviews, Mimosoideae and Papilionoideae have both been settled as monophyletic, settled inside a paraphyletic Caesalpinioideae. The paraphyletic subfamily Caesalpinioideae involves a various array of 'caesalpinioid' legumes that for the most part separated right on time in the historical backdrop of the family and need distinguishing floral attributes used to gathering genera into the other two families. The caesalpinioid tribe Cercideae is proposed to be one of the most primitive separating ancestries in the family (Bruneau et al. 2008). A clade including numerous other genera of Caesalpinioideae is sister to the subfamily Mimosoideae, and a clade involving these two gatherings is sister to the subfamily Papilionoideae. In the subfamily Papilionoideae, a few noteworthy gatherings have been recognized in light of molecular phylogenies (Legume Phylogeny Working Group 2013). The dalbergioid clade is a vast gathering of 45 genera and ca. 1270 species that incorporates the shelled nut (*Arachis hypogaea* L.). The genistoid clade comprises the genus *Lupinus* L. and additionally other various genera. The millettioid group involves the unequivocally sustained millettioid and phaseoloid clades including numerous vital crop species, for example, the cultivated soybean (*Glycine max*) and common bean (*Phaseolus vulgaris* L.). Hologalegina (a casual name) is the leading significant clades of Papilionoideae, divided into two main clades, namely, the robinioids (*Robinia L.* spp., e.g. dark grasshopper) and *Sesbania scop*. spp. The division is of importance due to stem-nodulation in a few species and the repeat-loss clade that is set apart by the loss of one duplicate of the vast (roughly 25 kb) inverted repeat normally found in the chloroplast genome of angiosperms. The herbaceous genera of Papilionoideae subfamily include natural plants, for example, *Pisum* L. (pea), *Vicia* L. (vetch, broad bean), *Cicer arietinum* L. (chickpea), *Medicago* L. (hay) and *Trifolium* L. (clovers). The biggest papilionoid subgroup in number of genera is the phaseoloid/millettioid assemble, which, as Hologalegina, incorporates various trained taxa, for example, *Glycine* L. (soybean), *Phaseolus* L. (basic bean), *Vigna savi* (cowpea, mung bean), *Cajanus cajan* (L.) Millsp. (pigeon pea) and *Psophocarpus* Neck. ex DC. (Winged bean). Connections in the gathering are perplexing and incorporate components of a few tribes. For instance, the nearest relatives of glycine, the soybean family, still stay obscure with a few hopefuls proposed by different atomic reviews including the pantropical variety *Teramnus* P. Browne, *Amphicarpaea*, the tribe *Psoraleeae* (Stefanović et al. 2009) or a mix thereof (Legume Phylogeny Working Group 2013).

Could the high CO_2 levels imply that N would get to be distinctly constraining for plant development, accordingly supporting advancement of N fixation? Positively, this period denoted the starting point of two main group of nodulating legumes, the genistoids and dalbergioids, and in addition group of caesalpinioids that comprises nodulating genera. In the event that nodulated legumes advanced under states of high CO_2, then it may be normal that they would be supported by current ascents in climatic groupings of this gas. Legumes abundance has main impacts on the rate of carbon and nitrogen in biological communities. Legume crops that are indigenous to Africa range from large rain forest tree to small annual herb (Sprent et al. 2009). Those genera whose major centre of diversity is Africa will be discuss in turn.

3.11.1 *Vigna*

Vigna is a genus that belongs to the popular tribe called Phaseoleae, and it is made of about 100 species some of which include *V. radiata* (L.) R. Wilczek, (also known as mung bean), *V. mungo* Hepper, *V. heterophylla*, *Vigna marina* (Burm.) Merr., *V. luteola*, *V. subterranean*, *V. vexillata* and *V. unguiculata.* Some of the species are annual, while some other ones are perennial. They are all herbaceous with some climbing (Sprent et al. 2009). *Vigna* are valued for their tuber or seeds. They are used for human food, medicine, soil improvement and for animal feed. *V. subterranean* for instance is used for breeding salinity tolerance into other crops. *Vigna* are reported to nodulate freely, using mainly the slow-growing bradyrhizobia.

The most prevalent farming system in Africa is the small-scale characterized by mixed crop-livestock farming. In this system, legumes are incorporated into both the crop and the livestock component. Through the process of BNF, legumes have the ability to increase soil fertility and protein levels in herbage. Legumes can form tripartite symbiotic relationship with nodule-inducing rhizobia and arbuscular mycorrhizal fungi. The rhizobial symbiont is responsible for atmospheric nitrogen fixation, while the association with arbuscular mycorrhizal fungi improves the ability of the plant to take up P and other nutrients (Marcel et al. 2008).

3.11.2 Cowpea

Cowpea (*Vigna unguiculata*) is one of various species of the popularly grown genus *Vigna*. Cowpea is one of the most important food and animal feed crop commonly cultivated in the semiarid tropics covering Africa, Europe, Asia and the United States. It originates from Africa and is one of the most productive heat adapted legume used agronomically. Grain ranges from 392 to 3024 kg/ha^{-1}. Use metric unit and report in kg/ha or t ha^{-1} and provide reference to support the yield statistics.

Cowpea is valued as a nutritional supplement to cereals because of complementary protein types. It is cultivated by multiple millions of smallholders in Africa. In fact, it is estimated that 200 million children, women and men live off the plant consuming the seeds daily whenever available (National Research Council 2006). Widely appreciated by the poor, cowpea seed is rich in protein, oil and digestible carbohydrate (Adeyemi et al. 2012; El-Jasser 2011; Sebetha et al. 2010).

3.11.3 Soybean

Soybean (*Glycine* max) is an annual summer legume used as human food, livestock feed and for several industrial purposes (Ali 2010). Soybean is cultivated majorly for its oil extraction (Morel et al. 2012).

3.12 Northern Africa

The major food legume in North Africa is faba bean followed by chickpea. Others include groundnuts/peanuts, lentil soybean and pea.

3.13 West Africa

Nitrogen-fixing plants have contributed to the improvement of soil fertility in West Africa. Herbaceous and woody legumes such as X, Y and Y (examples) commonly contribute 40–70 kg N ha^{-1}, which represents about 30% of the total N applied as residues (Sanginga 2003). Soybean was first cultivated in Africa in the early twentieth century and was introduced to Nigeria in 1904. Soybeans are being used to develop sustainable cropping systems in the moist savannah. The N_2 fixed by soybeans and their residual N benefits to subsequent cereal crops in the savannah zone of Southern Guinea have been estimated to vary between 38 and 126 kg N ha^{-1} (Bala 2011).

Planted forage legumes were introduced into West Africa in 1950. In the course of intensifying mixed crop-livestock systems, the dual-purpose varieties of annual (food-feed) legumes (mainly cowpea and groundnut) have gained popularity, especially in areas where farmers have good market access and pressure on land is high (Blummel et al. 2016).

Nitrogen depletion from West African soils poses serious threats to food production. There is however the need to increase food production to meet the basic food requirement of the teaming population. The use of inorganic N fertilizers though increases food production, is however not sustainable because of their indirect negative impact on soil in the form of soil degradation in the long run. Degradation in the long run is due to 'inaccurate use' such as 'application of excessive amount and the use of the wrong fertilizer type', which are collectively described as 'fertilizer abuse'. The health harzard fertilizer abuse pose to man and animal through underground water pollution is a concern (Alori et al. 2017)

The use of imported microbial inoculants was initiated in West Africa in the 1970s. At first, there was poor response to the inoculants, because of incompatibility in the new environment. Several studies on the use of these inoculants were conducted on soybean (*Glycine max* (L.) Merrill) and cowpea (*Vigna unguiculata* (L.) Walp.) but rarely on Bambara groundnut (*Vigna subterranea* (L.) Verdc.) and groundnut or peanut (*Arachis hypogaea* L.) that are naturally more adapted and promiscuous (Svubure et al. 2010). Despite the fact that inoculation activities was initiated in sub-Saharan Africa since the 1950s, and mainly used on soybean and forage legumes, the adoption of inoculation on a commercial scale has not been widely adopted, except in a few countries. Bala et al. (2011) reported the use of inoculation in most parts of East (Kenya, Uganda and Tanzania) and Southern Africa (Republic of South Africa and Zimbabwe) where their agricultural sector is dominated by commercial farms. Regular use of microbial inoculant by farmers in West Africa is still very rare. The use of microbial inoculant and inoculant technology in West Africa is limited to research farms (Bala 2011) with scanty record at farmers' level due to the absence of or very limited large-scale soybean production and an intensive livestock industry (Bala et al. 2011).

3.14 Future Prospects and Recommendations

It is imperative for future research to identify how the exploration of legume microbial inoculants may be optimized. In addition, advances in molecular biology that will broaden knowledge base on the processes and functionality of the diverse microbiome within the rhizosphere are needed to promote widespread adoption of legume microbial inoculant in Africa agriculture will be a welcome idea. Isolation, characterization and selection of effective strains to develop local inoculant for each legume under diverse climatic and soil conditions will improve legume cropping systems in Africa.

3.15 Conclusion

The roots of legume and nonlegume plant harbour diverse microorganisms that are able to establish mutual relationship with plant root. Microbial inoculants comprising rhizobia and endophytes are potential resources that should be maximized to enhance the production of African legumes at minimal cost.

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