Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.5, No.12, 2015

Worldwide Contrast in Application of Bio-Fertilizers for Sustainable Agriculture: Lessons for Sub-Saharan Africa

Cargele Masso[1*] Juliet R. Awuor Ochieng[1, 2] Bernard Vanlauwe[1]
1.International Institute of Tropical Agriculture (IITA), c/o ICIPE, Kasarani, P.O. Box 30772-00100, Nairobi, Kenya
2.Centre for Advanced Studies in Environmental Law and Policy, University of Nairobi, P.O. Box 30197-00100 Nairobi, Kenya
* E-mail of the corresponding author: C.Masso@cgiar.org

Abstract
The use of bio-fertilizers in sub-Saharan Africa (SSA) is low compared to selected developed and Asian countries. The later have perceived the products as useful and have invested in use of bio-fertilizers in their agricultural systems. Effective regulations in developed and selected Asian countries have enhanced the availability of high quality products. Conversely, lack of awareness, infrastructure, skill and absence of a supportive regulatory framework in SSA has negatively impacted the use of bio-fertilizers. This review aims at pointing out what SSA could learn from selected developed and Asian countries to improve the availability and adoption of high quality bio-fertilizers. The benefits in terms of biological nitrogen fixation, nutrient uptake, yield increases, cost saving, and utilization constraints are discussed to create awareness of stakeholders interested in the agricultural application of the technology in SSA.
Keywords: bio-fertilizer, availability, adoption, profitability, sub-Saharan Africa

1. Introduction

With the anticipation of an increase in the amount of N used in agriculture due to increasing population and food demand, excess application of chemical N fertilizer and its negative impact on the environment can be reduced through biological nitrogen fixation (BNF) (Gupta et al. 2007; Olivares et al. 2013). BNF is enhanced through inoculation. According to Qureshi et al. (2009), rhizobium legume inoculation has been practiced in agricultural systems for more than a century. Such inoculants can also be simply termed as bio-fertilizers (Mulongoy et al. 1992).

Bio-fertilizers are valuable to the environment as they enable reduced use of chemical fertilizers in the production of crops in different parts of the world. They are defined as products containing natural occurring micro-organisms that are artificially multiplied to improve soil fertility and crop productivity (Mazid & Khan 2014). Insufficient use of inorganic fertilizers in sub-Saharan Africa (SSA) mainly because of accessibility challenge has contributed to nutrient depletion and consequently land degradation (Graham & Vance 2003; Sutton et al. 2013); if bio-fertilizers were available, they would partially offer a potential solution to the issue as they are considered cost-effective (Ghosh 2003).

All types of crops grown in different agro-ecologies can benefit from the use of bio-fertilizers (Amutha 2011). Continuous use of bio-fertilizers enables the microbial population to remain and build up in the soil and helps in maintaining soil fertility contributing to sustainable agriculture (Choudhury & Kennedy 2004; Malik et al. 2011). Growing crops using bio-fertilizers is advantageous in protecting the soil from degradation. By 2018, the worldwide market for bio-fertilizers is expected to exceed a market worth of US$ 10.2 billion; Europe and Latin America are the top consumers due to availability of stringent regulations imposed on chemical fertilizers, followed by Asia-Pacific which controlled 34% of the market as by 2011 (Raja 2013).

Despite the opportunity, bio-fertilizers are barely used by smallholder farmers in SSA (Chianu et al. 2011). There is an overdue need to understand the limiting factors, but also to highlight the opportunities so as to inform policy decisions. Therefore, the objectives of this review are to outline: (i) the main constraints to the availability and adoption of bio-fertilizers in SSA, (ii) the lessons that SSA could learn from selected developed and Asian countries and (iii) the opportunities offered to SSA following the adoption of bio-fertilizers.

2. Constraints to the Availability and Adoption of Bio-fertilizers in SSA

Numerous benefits exist with the incorporation of bio-fertilizers into agricultural systems. However, hurdles have been reported in the use of the products thus reducing their uptake in SSA. Variability experienced in the field arises from non-specific host-inoculant relationships, different physical and chemical edaphic conditions, poor competitive ability against native strains, and a deficiency of adequate formulation (Lucy et al. 2004). Understanding how such factors affect BNF performance in the context of SSA could improve the efficiency of legume technologies, and consequently the adoption of the practices, so that smallholder farmers in SSA can have access to the same opportunities as farmers in selected developed and Asian countries. Furthermore, appropriate soil amendments, both green and farmyard manure, enhance the exploitation of bio-fertilizer benefits as they are important in achieving better crop growth, nodulation and yield (Javaid & Mahmood 2010). For instance, the efficiency of plant-associated N fixation by diazotrophic bacteria may be hampered by a limited supply of energy and substrates (Choudhury & Kennedy 2004). The use of organic sources of nutrients is important as it draws the benefits of BNF. There is need for such knowledge to be disseminated among farmers. The main constraints highlighted in this review include agro-climatic, technological, as well as regulatory and market issues.

2.1 Agro-climatic Constraints

Field performance of bio-fertilizers such as *rhizobium* inoculants is affected by several factors including the crop genotype, the micro-organism strain in the bio-fertilizer, the environmental conditions (i.e. soil and weather), as well as the agronomic management (Şahin et al. 2004; Çakmakçi et al. 2006; Woomer et al. 2014). The application of bio-fertilizers in agricultural production in SSA is gaining momentum but more research is required to obtain the benefits. This could substantiate the significant spatial- and temporal-variability of crop responses (Singleton et al. 1992; Babalola & Glick 2012) due to poor understanding of where and when to apply bio-fertilizers, which may have contributed to the little adoption of the technology (Hedge et al. 1999). The effectiveness of the products has to be tested in variable conditions including abiotic stresses such as drought, soil acidity or low soil fertility (Banayo et al. 2012) to develop adequate recommendations for use.

Selected causes of variability in crop response to bio-fertilizers

- Edaphic characteristics such as soil pH, nitrogen (N) and phosphorus (P) availability
- Drought

These factors display the importance of structured research studies in order to enhance benefits that can be obtained from the use of bio-fertilizers in the SSA context.

Box 1 Selected Agro-climatic Conditions Affecting Crop Responses to Bio-fertilizers

2.1.1 pH

Soil pH affects: (i) the population of micro-organisms, (ii) the survival of the strain, and (iii) nutrient availability. Table 1 displays the effect of pH and its relationship to the availability and survival of beneficial micro-organisms in bio-fertilizers applied to the soil.

Table 1. Effect of pH on the Population and Survival of Beneficial Micro-organisms

Indicator	Increased acidity ←	Increased alkalinity →	Reference
Population of beneficial micro-organisms (Rhizobia)	Low	High	Gupta et al. 2007
Strain survival	Low	Low at pH > 8.5	Howieson & Ballard 2004

Soils with low pH do not encourage a healthy population of micro-organisms beneficial to plant growth. Legume response to inoculation in the soils of East and Southern Africa is prohibited by the low population of indigenous *rhizobia* in these soils which changes with the ecological zones and land use practices (Woomer et al. 1997). Limited availability of nutrients such as P and Mo negatively affects nodulation and reduces *rhizobia* population (Giller 2001; Peoples et al. 1995), thus having a negative effect on BNF. In mineral soils, the pH window of maximal P availability is quite small (i.e. 6.5–7.0) though the situation is relatively acceptable for $5.5<pH<7.5$, whereas the availability of Mo increases with the pH particularly at pH levels > 7 and drastically decreases at pH <5.5 (Wolf 1999). High reactivity of phosphate with aluminium, iron and calcium, and the subsequent precipitation makes it unavailable to plants (Gyaneshwar et al. 2002). In field conditions with acidic pH (Rengel 2002) and low phosphorus (Mullen 1988), the nodulation process is adversely affected. As most African soils are acidic, lime could be used to improve the pH (Fairhurst 2012), but majority of the smallholder farmers do not use it mainly because of unavailability and insufficient awareness.

The effect of soil pH may however depend on the type of bio-fertilizers. In a study using *Vesicular arbuscular mycorrhiza* in acidic and low fertility soils in southeastern Nigeria, it was realized that there is enhanced N and P uptake (Effiong & Ibia 2009). In Asia, after several field experiments using cyanobacteria on different types of soils in Bangladesh, it was found that urea N inputs could be reduced by 25–35% with application of bio-fertilizer in the cultivation of rice in acidic and saline soils; however, the product was less effective in calcareous and neutral soils (Hashem 2001). The efficacy of a bio-fertilizer thus depends on whether the strain can survive in the field conditions. There is a need to understand the optimum pH for each type of bio-fertilizer in the various agro-ecologies of SSA.

2.1.2 Nutrient Availability

The application of P fertilizers in combination with bio-fertilizers increased soybean yields by ≈47% over the negative control in soils with low P in SSA (Woomer et al. 2014). Rhizobial activity and BNF is enhanced by increased availability of P (Giller 2001; Zaidi et al. 2003; Khan et al. 2009). Hence, P is among the limiting nutrients for legume BNF in most plants (Vance 2001; Mulas et al. 2013). Nevertheless, selected bio-fertilizers have shown the ability to improve the plant P uptake (Table 2). Co-inoculation of effective *rhizobia* inoculants and bio-fertilizers intended to improve P availability and uptake may therefore improve BNF efficiency.

Phosphorus and potassium (K) in arid saline soils of China are available only in limited amounts and use of P solubilizing bacteria showed improved availability of the nutrients (Ullmann et al. 1996). Application of rock phosphate together with P solubilizing micro-organisms could improve P availability (Khan et al. 2009). In India, following the improvement of the performance of chemical P fertilizers by Phosphate Solubilizing Bacteria (PSB), some companies have promoted increased sales of chemical fertilizers alongside bio-fertilizers (Pray & Nagarajan 2012). Combination of bio-fertilizers and low cost fertilizer materials such as rock phosphate may represent an important opportunity for smallholder farmers in SSA who generally may not afford the price of inorganic P fertilizers.

Table 2. Enhanced P Uptake through use of selected Bio-fertilizers

Bio-fertilizer	Activity and Benefit	Reference
Mycorrhiza	Increased root surface area for exploration and the production of phosphorus solubilizing enzymes and organic acids	Njira 2013
	Improved photosynthesis due to increase in transporting inorganic elements to plants	Mehrvarz et al. 2008
	Increased P availability from very low concentrations	Jha et al. 2012
Phospho-bacterium and Mycorrhiza	Increase P availability	Suja 2008
Rhizobium and Phosphobacterins	Enhanced P uptake by 16.9% in seed and 21.7% in stover	Dutta & Bandyopadhyay 2008
Blue-green algae (BGA)	Increased efficacy of rock phosphate	Mandal et al. 1999
P solubilizing bacteria (PSB)	Increased P availability	Khan et al. 2009
Aspergillus niger 1107 phosphate-solubilizing fungus (PSF)	Increased root and dry weight Increased P availability	Wang et al. 2014

2.1.3 *Drought*

Bio-fertilizers can prove to be of benefit in drought prone areas where the products enable the crops grown to survive in such stressful environments through improved water use-efficiency (Table 3). This potential should be exploited to select effective strains in SSA, which often experiences seasonal drought episodes that significantly contribute to the current yield gaps. In Sudan for instance, *rhizobia* inoculation has been shown to improve the yield of alfalfa, fenugreek, cluster bean, field pea and common bean grown in drought conditions (Abdelgani et al. 2003).

Table 3. Mechanisms of Action of Selected Bio-fertilizers to Improve Crop Resistance to Drought

Environmental condition	Bio-fertilizer type	Activity and benefits	Reference
Drought	Mycorrhiza (AMF)	Enhancing the host's osmotic adjusting capability resulting to continued water uptake even as soils become drier enabling survival in drought conditions	Tiwari 2004
		Increased photosynthesis and better osmotic adjusting of crops under drought stress	Al-Karaki 2006
	Rhizobium	Production of phytohormones which change the root physiology and morphology resulting to increased nutrient and water uptake	Mia & Shamsuddin 2010
		Enhanced nodulation, dry weight of nodules, nitrogen fixation and yield	Abdelgani et al. 2003

2.2 Technological Constraints

The dividing line between selected developed and Asian countries on one hand and SSA on the other is at the point where the earlier have devoted resources to research, increased awareness, adequate formulation and production, subsequently increasing the use of bio-fertilizers. A prevalent barrier to the commercialization of bio-fertilizers is inadequate formulation of the products (Smith 1992; Stephens & Rask 2000). In SSA most of bio-fertilizers in the marketplace are imported and generally not tailored to the local conditions in terms of shelf-life and storage conditions especially by smallholder farmers. For instance, some bio-fertilizers require storage in a cool place (e.g. refrigeration) for an extended shelf-life. This is not suitable in SSA, where temperatures are usually quite high and access to refrigerators or power is a huge challenge. This may substantiate why the majority of products found in the marketplace in Ethiopia, Kenya and Nigeria could not meet the quality standards (Jefwa et al. 2014; Masso et al. 2014).; probably as a result of loss of viability in the harsh conditions.

Product formulation, taking into consideration product shelf-life under variable storage and handling conditions is critical (Mahdi et al. 2010; Kumar 2014), especially in the SSA conditions. Even in countries with significant government support to the bio-fertilizers sector, such as India, product shelf life, quality of carrier materials, storage conditions (e.g. temperature), handling (e.g. transportation) (Chen 2006; Tan et al. 2009), as well as the presence of contaminants (Sivasakthivelan & Saranraj 2013) affect the field performance, and consequently the adoption rate. It is thus important to improve the shelf-life of locally formulated bio-fertilizers (Bramapakash & Sahu 2012; Kumar 2014) in various storage conditions to ensure product viability over a significant time period.

The demand for high quality inputs may trigger innovation improvement. In SSA, for example in Eastern Africa, low demand due to lack of awareness and understanding of bio-fertilizers has resulted in poor development of the bio-fertilizer sector (Schulte-Geldermann 2013). Despite the potential of bio-fertilizers in SSA, local production remains a challenge, not only because of the cost of production (Harman 2010), but also the limited demand, as well as poor delivery mechanisms (Odame 1997) that could be associated with the particular requirements for handling and storage conditions. Less than 1% of farmers use inoculants in Kenya as revealed by a survey in East and Southern Africa (Karanja et al. 2000), which had been related to insufficient awareness creation (Woomer et al. 1997). This contrasts with the occurrence in Brazil, where almost all the crop protein produced is through BNF as a result of inoculation (Alves et al. 2003). Therefore, SSA faces a challenge of improved formulations tailored to local conditions and poor understanding of the technology; consequently minimum availability and adoption. Without extensive research to develop formulations that could cater for the spatial and temporal variability of crop responses (Uribe et al. 2010), SSA will not be able to benefit from the full potential of bio-fertilizers. When suitable technologies for SSA are identified, the industry may also have to consider small packets relevant to smallholder farmers (Chianu et al. 2011), considering the farm sizes, the ability to pay, and the high risk of contamination of bio-fertilizers once a packet is open. Importantly, to ensure that proven technologies don't compete with poor quality bio-fertilizers in the marketplace, effective regulations for improved quality control are required (Harman 2010) to promote fair trade and market growth for bio-fertilizers in SSA.

2.3 Regulatory and policy constraints

Quality control and regulation of bio-fertilizers is important to ensure conformity to prescribed standards, product safety and efficacy (Banayo et al. 2012; Desyane & Wiyana 2012). Poor quality bio-fertilizers can be expected in the market when the quality control framework is not well-defined, resulting in poor field performance (Catroux et al. 2001; Herridge et al. 2002). In SSA, lack of effective regulation of bio-fertilizers is among the greatest contributors to low availability and adoption of the products dissimilar to the situation in selected developed and Asian countries.

Research to improve the agricultural application of bio-fertilizers is still at the infant stage in most SSA countries and is derailed through lack of awareness, infrastructure and human capacity (Dhlamini et al. 2005; Njira 2013), as well as the absence of a supportive regulatory and policy framework (Ochieng 2015). In SSA, the potential benefits of bio-fertilizers remain largely untapped due to inadequate national policy and regulatory framework (Simiyu et al. 2013). Low demand for bio-fertilizers in SSA is possibly a result of the regulatory environment. Adherence to specified quality standards by manufacturers is important to ensure only adequate quality products are allowed to circulate in the market.

Periodic monitoring of products in the market is important to ensure product quality in the full commercialization chain and avoid adulteration of products by unreliable businessmen (Enti-Brown et al. 2012). Lack of continuous market monitoring has contributed to the presence of poor quality bio-fertilizers in the Kenyan market and consequently low demand of the products by famers (Ochieng 2015); a similar situation is expected in a majority of the SSA countries.

Another hurdle in the use of bio-fertilizers in SSA is the difficulty in getting a new product registered. Poor management of fertilizers and supplements (e.g. bio-fertilizers) registration can create roadblocks to innovation and limit accessibility to novel products that otherwise would have improve farmers' competitiveness (Canadian Fertilizer Products Forum 2007). Selected developed and Asian countries have established appropriate regulations in order to control for such difficulties and create a favourable business environment for bio-fertilizers. For example, the Canadian Food Inspection Agency (CFIA) has well-defined procedures accepted by the industry for the registration of bio-fertilizers. Such clear administrative processes allow businessmen to operate in a secure environment and can also attract new investors in the bio-fertilizer industry. However, in many SSA countries such as Kenya, no such administrative guidelines have been made available through regulations, resulting in difficulties to introduce new bio-fertilizer products in the market (Ochieng 2015).

During the years 2009 to 2011, an assessment on bio-fertilizer products in Kenya, Nigeria and Ethiopia (three SSA countries), revealed that 90% of the product formulations did not match the product labels due to the absence of the active ingredients or the presence of contaminants (Jefwa et al. 2014; Masso et al. 2014). Enforcement of quality standards could significantly contribute to mitigating the challenge (Desyane & Wiyana 2012; Ochieng 2015). Well-defined requirements for quality would also facilitate the approval process of bio-fertilizers (Babalola & Glick 2012), by reducing delays related to the 'fear of the unknown', which is common in selected SSA countries with relatively weak regulatory frameworks for bio-fertilizers. Countries like Zimbabwe and South Africa have mandated the national biotechnology institutions to address the bio-safety issues (Brenner 1996) to ensure that products are safe to plants, animals, humans and the environment, while creating an enabling environment for innovation. Improving the technical and human capacity for quality control of bio-fertilizers has also been identified as critical for adequate marketplace monitoring (Mahdi et al. 2010; Bhattacharyya & Tandon 2012). It is only recently that a few countries in SSA have started to improve such capacity (Simiyu et al. 2013; Tarus et al. 2014). Supportive government policies therefore appear important to ensure that only high quality bio-fertilizers are legally sold in the various SSA countries.

Selected Asian countries have achieved increased use of bio-fertilizers through support of the government. For example, the production and use of bio-fertilizers in Thailand drastically increased as a result of the support of the Ministry of Agriculture to the sector (Kannaiyan 2003). A similar government initiative was reported in India (Ghosh 2003). The insufficient regulatory framework in SSA countries, such as in Kenya, has created a weak foundation for government support in increased use of bio-fertilizers in the countries (Ochieng 2015). Conversely, in South Africa, the first commercially manufactured inoculant was produced in 1952 and due to poor quality products in the market, an independent quality control system was introduced in the 1970s to ensure that the products could match best quality inoculants produced outside the country (Strijdom 1998). Importantly, regional trade could probably be facilitated when quality standards are at par among the different SSA countries and even developed countries. Given the current trend to harmonize standards in SSA for agricultural inputs (USAID 2012; COMESA 2014), the discussions should be extended to bio-fertilizers. It is worth recommending to align the standards with those in countries with significant history of bio-fertilizers use such as India, South Africa, New Zealand, France, Australia and Canada among others, to improve consumer protection, while facilitating trans-boundary trade. For instance in these countries, *rhizobium*-based inoculants should contain at least $5 \times 10^7 - 10^9$ colony forming units (cfu) of the active ingredients (i.e. micro-organism strains) per gram of the bio-fertilizer product (Boonkerd 1991; Catroux 1991; Thompson 1991; Smith 1992; Jha et al. 2012; Bhattacharyya & Tandon 2012), whereas no contaminants should be detected at 10^5 dilutions for products sold in India (Bhattacharyya & Tandon 2012).

In selected countries such as Australia, Canada, China, New Zealand, Thailand, the United States of America, as well as most of the countries in the European Union, the self-regulation of the bio-fertilizer industry has been found promising (Smith 1992; Catroux et al. 2001; Alten et al. 2002; Herridge et al. 2002; Khokhar 2012; CFIA 2013). This represents a significant challenge in SSA as the sector is not well-organized; costumer-paid service is being promoted instead to ensure that the industry pays for the quality control as promoted by the International Institute of Tropical Agriculture (www.compro2.org; date retrieved 01 May 2015). In countries like Canada, France and Uruguay, the government plays a role in the quality control of bio-fertilizers. For instance, in France despite the long history of bio-fertilizer use in agricultural production (Ravensberg 2013), manufacturers are still required to generate sufficient data to support the quality, efficacy and safety of novel products (Giazinnazi & Vosatka 2004). Countries in SSA could therefore build on the experience of others and aim at establishing effective regulations to increase availability and adoption of bio-fertilizers, while facilitating market growth in the region.

2.4 Market opportunity constraints

Besides effective regulation of bio-fertilizers, market growth is equally important for increased availability and use of bio-fertilizer products (Giazinnazi & Vosatka 2004). The volatility of the inputs and outputs markets in SSA (Nziguheba et al. 2010), may partially explain the minimum availability and adoption of agricultural inputs including bio-fertilizers. In general, when farmers obtain a value cost ratio higher than three to four, the willingness to adopt a novel agricultural technology increases (Dittoh et al. 2012) as a result of the market opportunities.

In SSA poorly developed marketing channels and infrastructure, and limited involvement of the private sector in the distribution of inoculants as well as limited farmer awareness about and access to inoculants has impacted the bio-fertilizer market negatively (Chianu et al. 2011). Farmers can get awareness of the bio-fertilizer technology through: (i) efforts to increase the availability of the products, (ii) research and extension for education, and (iii) effective marketing strategies (Banayo et al. 2012). Countries in SSA can learn from selected developed and Asian countries that have succeeded in enhancing bio-fertilizer market growth. This is particularly important as bio-fertilizers provide an affordable industry for many developing countries (Tiwari et al. 2004), which could be set at different locations within a country to reduce the distribution costs, and consequently the costs of the products. For instance, with the increased soybean cultivation in Brazil in the 1960's, application of bio-fertilizers (i.e. *rhizobium* inoculants) was immediately adopted (Dobereiner 1997; Hungria & Campo 2007). Use of *rhizobia* inoculants in North America is a practice that has been continuing for more than a century (Chandler et al. 2011). The European Union encourages the use of bio-fertilizers by advising farmers to optimize the application of chemical fertilizers or replace them partly or completely with bio-fertilizers that are considered environmentally friendly (Ivanova et al. 2004).

Lack of awareness of bio-fertilizers is a major challenge in SSA for farmers, private sector (i.e. agro-dealers), extension services and policy makers among others. Insufficient understanding of the technology hampers the diffusion of innovation that could have otherwise been facilitated by awareness creation through dissemination of information by extension agents, radio, television and neighbours (Nwaobiala & Ogbonna 2014; Ochieng 2015). There is an overdue need for the national and international research organizations, as well as the bio-fertilizer industry to improve the awareness of the key stakeholders through participatory demonstration trials. Those stakeholders could then train farmers in their communities. Demonstration trials in different areas are a strategy to increase awareness and the use of novel products by farmers (Cong et al. 2011); they are more useful when a participatory approach is used to include various stakeholders (Wahab 2009).

In Asia, government support has played an important role in promoting the increased use of bio-fertilizers among farmers and market growth for the products. In India for instance, bio-fertilizers are supported by the government through a national project on development and use of the technology. Zonal production facilities, state departments and state agricultural facilities, public sector firms and cooperatives also produce bio-fertilizers. Private industries obtain subsidies from the government to cover the cost of plant and equipment for production. In addition, the governments purchase large portions of the products for distribution to farmers ensuring a continuous market for producers (Venkataraman & Tilak 1990; Alam 1994). Such incentives have contributed to the promotion of the bio-fertilizer business sector in India (Mishra & Dash 2014). Manufacturers have also formed an association (i.e. All India Biotech Association) to coordinate the commercial sector's voice in developing government policy. In addition, non-governmental organizations (NGOs) such as the M.S. Swaminathan Research Foundation, and international research centres such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Rice Research Institute (IRRI), have also contributed to the increased use of bio-fertilizers (Rabindra & Grzywacz 2010). All these cumulative activities by the government, research institutions and industry players have put India at the forefront in the use of bio-fertilizers. In 2005, a total of 170 of the 300 bio-fertilizer production units in the world were in India and the private sector run 147 of these units (Tiwari 2005).

Combined efforts of the NGOs, private and public universities, international research organizations such as the International Center for Tropical Agriculture (CIAT), the government, and the private sector also resulted in significant growth of the inoculant industry in Colombia (Moreno-Sarmiento et al. 2007). Conversely, weak linkages with private sector manufacturers, local stockists, NGOs and smallholder farmers, and poor support of production, distribution and use have affected the availability and adoption of bio-fertilizers in SSA (Odame 1997; Simiyu et al. 2013). Therefore, the bio-fertilizer market growth in SSA will require a strong public–private partnership and enough commitment to improve. Lessons learned elsewhere combined with sufficient awareness creation may be useful to build the partnership to increase the awareness and understanding of the technology. As the profitability of bio-fertilizers is demonstrated through participatory demonstration trials and output markets, the demand is expected to increase, and consequently the bio-fertilizer (i.e. input) market.

3. Opportunities in the Use of Bio-fertilizers

Selected developed and Asian countries have successfully adopted the use of bio-fertilizers in their agricultural systems (Ramesh et al. 2005) by addressing most of the constraints mentioned above, and consequently improving the field performance of the products. Better understanding of the benefits realized by farmers in those countries could be useful to regulators and policy makers in SSA to inform their policy decisions related to research on, regulation and awareness creation of bio-fertilizers. Opportunities associated with bio-fertilizer application in agriculture include BNF, crop yield increase and economic return, among others.

3.1 BNF Potential

Agricultural yields in SSA are greatly affected by low soil N fertility (Belane & Dakora 2010). Farmers in SSA engage in nutrient mining through cropping without replacing the exported nutrients by effective use of fertilizers or organic manure (Sanchez 2002). High cost of inorganic fertilizers is one of the main explanations provided by farmers to substantiate the insufficient use of inorganic fertilizers (Dittoh et al. 2012). The average application rate is 10 to 26 kg ha^{-1} (Dittoh et al. 2012; Sheahan & Barrett 2014) of all nutrients combined. BNF through application of legume technologies including *rhizobia* inoculants ought therefore to hold greater importance in SSA (Nicolas et al. 2006). The practice of inoculation is common in countries like Brazil, Israel, USA, Germany and China (Sinha 1998). Brazil and Argentina, two largest producers of soybean in the world, are heavily dependent on the use of bio-fertilizers in their soybean cropping systems (Uribe et al. 2010).

Soil fertility is improved through the process of BNF (Okon & Labandera 1994). BNF is a potential source of N in agro-ecosystems and it represents an economic, sustainable and environment-friendly source in comparison to chemical fertilizers (Herridge et al. 2008). The natural process of BNF is important in sustainable crop production systems as it accounts for 65% of the nitrogen currently used in agriculture (Matiru & Dakora 2004). BNF is a potential source of N in agro-ecosystems and it represents an economic, sustainable and environmentally-friendly source in comparison to chemical fertilizers (Herridge et al. 2008). Where farmers face constraints in the appropriate use of chemical fertilizers, such as in most of the SSA countries, BNF is considered as a viable source of N in grain legume production (Chianu et al. 2011). According to Ishizuka (1992), the yearly amount of nitrogen fixed biologically is 100–175 million metric tons, while the amount of N contributed by chemical fertilizers to the soil is only 40 million tons. Graham (1988), stated that 80% of BNF comes from symbiotic associations, while the remainder is from free-living systems. Free living nitrogen-fixing bacteria such as *Azotobacter* and *Azospirillum* have the ability to fix upto 10–20 kg N ha^{-1} (Ramakrishnan & Buneswari 2013). For optimum BNF, legume crops with the ability to fix N should be promoted (Graham et al. 2004), and the use of N fertilizers should be avoided or reduced (Mandal et al. 2009). According to Mugabe (1994), tapping into the BNF can save expenditure on fertilizer imports ensuring sustainable and low cost of production in Africa. BNF is and will remain absolutely beneficial to agricultural systems of smallholder farmers in Africa that use little or no farmyard manure and chemical fertilizers to improve soil nutrition (Mapfumo 2011). This is especially important in SSA as the soils are depleted and lack important nutrients for proper plant growth and development (Simanungkalit et al. 1996). Application of legume technologies to improve BNF was reported to also benefit the subsequent cereal crops used in rotation such as maize and to allow saving on N fertilizers for similar or improved maize yields (Waddington et al. 2004; Mapfumo 2011).

Non-legumes can also benefit from the BNF process. A number of researchers have experimentally demonstrated the ability of *Rhizobia* to colonize roots of non-legumes and localize themselves internally in tissues, including the xylem (Spencer et al. 1994). These include crops such as radish (Antoun et al. 1998), rice, wheat and maize (Webster 1997; Yanni et al. 2001). *Rhizobia* induce nodule-like structures on the roots of rice, wheat and oilseed rape seedlings (Cocking 2000). The association of sugarcane and rice with bacterial diazotrophs that infect, multiply and spread inside the roots and aerial parts of such non-legume crops is another example of direct benefits from BNF (Olivares et al. 2013). BNF has also been exploited in Pakistan on rice and a yield increase of between 19–58% recorded depending on the strain and rice cultivar tested (Uribe et al. 2010). BNF can be improved through the optimal use of nitrogen-fixing systems, research and development of new fixing plant microbe associations and transfer of nitrogen fixing ability to non-fixing organisms (Olivares et al. 2013). Focus should be on sustainable exploitation of biodiversity of nitrogen-fixing organisms besides the legume–rhizobium symbiosis, as this will have important agronomic implications such as transfer of the nitrogen-fixing capacities to major non-legume crops (Santi et al. 2013). Research on the benefits of bio-fertilizer in SSA should therefore not only be confined to legumes but a wide variety of crops in order to tap into the potential of BNF in crop production.

An example of a country in SSA that has invested in increased use of bio-fertilizers is Zimbabwe. The country has a large and well-established soybean sector that makes use of inoculation (Mpepereki et al. 2000). A Soil Productivity Research Laboratory was set up in Zimbabwe with a yearly production capacity of 120,000 packets and the products are distributed to farmers through the government extension system. Other countries in SSA should learn from the experience of Zimbabwe and invest in full exploitation of BNF as it has great benefits to crop productivity, the environment, and in savings on chemical fertilizers. This could be achieved through adequate research to inform consistent response to bio-fertilizers across variable agro-ecological zones in SSA.

3.2 Yield Performance

Variable yields from use of bio-fertilizers have been recorded across global regions. Mpepereki et al. (2000), stated that soybean yields of 2,000 kg ha^{-1} have been achieved using BNF in Zimbabwe. However, BNF has resulted to yields higher than 4,000–6,000 kg ha^{-1} in both Brazil and Argentina (Zotarelli 2000; Hungria et al. 2006). This might be attributed to the difference in research investment to address other limiting factors including crop genotype, longer history in the use of bio-fertilizers and technology improvement, and availability of effective regulations to ensure bio-fertilizer quality among others; all these could directly or indirectly affect the BNF performance. Table 4 gives a brief outline of the crops grown in different countries and the respective yield increase as a result of bio-fertilizer use.

Table 4. Variable Yield Performance of Bio-fertilizers in selected Countries

Country	**Bio-fertilizer**	**Crop grown**	**Average yield increase [%]**	**Reference**
Bangladesh	*Bradyrhizobium*	Soybean	20	Satnet 2013
India	*Azospirillum, Vesicular Arbuscular Mycorrhiza (VAM), Phosphorus solubilizing bacteria (PSB)*	*Stevia rebaudiana*	22	Das & Dang 2010
Vietnam	*Rhizobium*	Peanut	14–18	Nguyen 2006
Mexico	*Azospirillum sp.*	Corn seed	20–70	Caballero-Mellado et al. 1992
Iran	*Azotobacter* and *Azospirillum*	Canola	21	Yasari & Patwardhan 2007
Turkey	*Azospirillum brasilense Sp 246*	Wheat	15	Ozturk et al. 2003
	Azospirillum brasilense Sp 246	Barley	18	Ozturk et al. 2003
Colombia	*Azospirillum brasilense, A. amazonense* and *Azotobacter*	Rice	5–10	Moreno-Sarmiento et al. 2007
		Cotton	5–10	Moreno-Sarmiento et al. 2007
Egypt	*Vesicular arbuscular mycorrhiza*	Sweet fennel	21–24	Zaki et al. 2010
Kenya	*Rhizobia*	Soybean	15–30	Majengo et al. 2011

Similar to SSA countries, the cost of inorganic fertilizers in Iran is on the high side; researchers have been investigating the potential of complementing the chemical fertilizers with bio-fertilizers so as to reduce the application rate, while maintaining or improving crop yields (Yasari & Patwardhan 2007). As a result, growth and yield of tomato was increased with the application of bio-fertilizers together with chemical fertilizers in a field experiment (Direkvandi et al. 2008). According to Motsara et al. (1995), 20–200 kg N ha^{-1} can be added by bio-fertilizers in addition to their ability to release growth-promoting substances that could result in yield increase of 10–50%. Countries in SSA would probably benefit from similar research by identifying: (i) effective bio-fertilizers applicable to various crops grown in the region, and (ii) good agronomic practices to maximize their field performance.

3.3 Profitability

Higher nutrient use efficiency, benefit cost ratio, and reduced requirements for chemical fertilizers make bio-fertilizers profitable to farmers (Mishra & Dash 2014), in addition to the environmental benefits. Integration of bio-fertilizers in the current farming systems could contribute to sustainable agriculture (Faranak et al. 2013). This is particularly important in most SSA countries characterized by severe nutrient depletion associated with the lack or minimum use of fertilizers (Smaling et al. 2006; Cordell et al. 2009). As long as the cost of inorganic fertilizers remains quite high in SSA, particularly in the rural areas, and less profitable (Guo et al. 2009), bio-fertilizers will play a significant role when well-understood and correctly applied (Jetiyanon & Plianbangchang 2011). Evidence of profitability of bio-fertilizers in selected countries where they have been successfully applied may be useful to inform policy and farmers' decisions related to incorporation of bio-fertilizers into their agricultural systems (Table 5).

Table 5. Reduction of Chemical Fertilizer Use following Integration of Bio-fertilizers

Country	**Bio-fertilizer**	**Reduction of chemical fertilizer rate [%]**	**Crop**	**Reference**
India	PSB	25	Sugarcane	Sundara 2002
India, West Bengal	Azotobacter and PSB	25	Mustard (*Brassica campestris cv. B*	Mondal et al. 2015
Thailand	*Bacillus cereus strain RS87*	50	Rice	Jetiyanon & Plianbangchang 2011
Iran	Azotobacter	25	Black cumin	Valadabadi & Farahani 2010
Pakistan	K solubilizing bacteria *Bacillus mucilaginous,* Azotobacter, Azospirillum, Azoarcus and Zoogloea	50	Maize	Jilani et al. 2007
Colombia	*Azospirillum brasilense*, *A. amazonense* and Azotobacter	20–50	Cotton and rice	Moreno-Sarmiento et al. 2007
	Rhizobium (Rh) and *Bacillus megaterium* (BM3)	75	Snap bean	Gharib et al. 2009
Egypt	Azospirillum and Azotobacter	100	Okra	Shaheen et al. 2007
	Azotobacter sp., *Azospirillum sp.* and PSB containing *Bacillus sp.*	50	Flax	El-Nagdy et al. 2010
	Azotobacter and Azospirillum	100	Maize	Naseriad et al. 2011

In Brazil, great savings estimated to US$ 3 billion per cropping season are realized with the reduced need for N fertilizers through BNF (Nicolás et al. 2006). Coutinho et al. (2000), stated that inoculation with rhizobium in Brazil has resulted to a cost saving of US$ 1.3 billion in production cost. Soybean and other legumes are inoculated with rhizosphere bacteria instead of chemical nitrogen fertilization (Dobereiner et al. 1995). Such microbial inoculants increase nutrient use efficiency (Panwar et al. 2000). Chemical fertilizers have a low efficiency ranging 30–50% N, 25–40% P and 30–50% K due to losses to the environment (Sirmamata 2013), or fixation by the soil colloids. The nutrient use efficiency can be enhanced by use of Plant Growth Promoting Rhizobacteria (PGPR) or co-inoculants of PGPR and Arbuscular Mycorrhiza Fungi (AMF) (Bhardwarj et al. 2014). Fertilizer efficiency of all bio-fertilizers is ≥90% as there are very minimal losses due to leaching and fixation (Sirmamata 2013). Reducing the application rate of inorganic fertilizers when used together with bio-fertilizers (Table 5) may result in fewer nutrient losses, and consequently in both economic savings and environmental protection without negatively impacting the yields.

Farmers in selected developed and Asian countries generally apply excessive amounts of chemical fertilizers as a result of the low nutrient use efficiency (Pimentel et al. 2005). The cost of excessive inorganic fertilizer inputs in North America is estimated at US$ 2.5 billion per year (BANR/NRC 2003). Farmers in Europe and North America have applied generous amounts of chemical phosphorus and nitrogen fertilizers for a long period of time (European Fertilizer Manufacturers Association 2000; Roy et al. 2006). Aside from the high price tag, this practice has negatively affected human health and the environment thus the need to make agriculture environmentally and economically sound (Pimentel et al. 2005). Bio-fertilizers therefore offer a good opportunity to minimize such negative impacts on the environment and human health. For example, under the intensive farming system in Egypt, prevention of potential loss of N through leaching and significant increase in maize yield was achieved with the application of half the recommended N rate and bio-fertilizer, i.e. *Azospirillum* (Monem et al. 2001).

Reducing the application rate of chemical fertilizer following the integration of bio-fertilizers for similar crop yields is expected to result in better economic return given that bio-fertilizers are considered cost-effective (Jilani et al. 2007). Bio-fertilizers are many times cheaper than chemical fertilizers with a cost benefit ratio of more than 1:10 (Tiwari et al. 2004). Sirmamata (2013), reported that the application rate of chemical fertilizers could generally be reduced by 25–50% for nitrogen and 25% for phosphorus when appropriate bio-fertilizers are used without negatively affecting the yield performance. Further chemical fertilizer reductions have been reported in Egypt (Table 5). The various positive experiences in developed and other developing countries again support the need of further research in SSA to harness such benefits of bio-fertilizers, given the current low use of inorganic fertilizers, and improve awareness creation.

4. Conclusion

Despite the ability of bio-fertilizers to sustainably increase yields with significant economic benefit, they are not widely available to, and adopted by smallholder farmers in SSA. The greatest need for SSA is to invest in localized research, government support, involvement of the public and private sector in production of bio-fertilizers, increasing awareness of the products, establishment of effective regulations, and promotion of a favourable environment for bio-fertilizer market growth. Such hurdles have been overcome by selected developed and other developing countries (particularly in Asia) through adequate research to improve crop responses to bio-fertilizers under variable agro-climatic conditions, as well as policy and regulatory interventions intended to increase the development of bio-fertilizer technologies and market growth. Most of the lessons from those countries could be taken up by countries in SSA in order to increase the availability and adoption of bio-fertilizers among farmers.

5. Acknowledgements

The authors would like to acknowledge the financial support of the International Institute of Tropical Agriculture (IITA) through the COMPRO-II project to compile the review. They also appreciate the scientific contribution of the different authors cited.

References

Abdelgani, M.E., Osman, A.G. & Mohamed, S.S. (2003), "Restoring Soil Fertility of Desertified Through Biological Nitrogen Fixation", In Desertification in the Third Millennium, A.S. Sharhan, W.W. Wood, A.S. Goudie, A. Fowler & Abdellatiff, E.M., (eds.), A.A. Balkima Publishers, Lisse, the Netherlands, 335-338.

Al-karaki, G.N. (2006), "Nursery Inoculation of Tomato with Arbuscular Mycorrhizal Fungi and Subsequent Performance under Irrigation with Saline Water", *Scientia Horticulturae*, 109, Elsevier, 1-7.

Alam, G. (1994), "Biotechnology and Sustainable Agriculture: Lessons from India", OECD Development Centre Working Papers, No. 103, OECD Publishing, Paris.

Alten, H., Blal, B., Dodd, J.C., Feldman, F. & Vosatka, M. (2002), "Quality Control of Arbuscular Mycorrhiza Fungi Inoculum in Europe", In Mycorrhizal Technology in Agriculture: From Genes to Bioproducts, S. Gianinazzi, H. Schuepp, J.M. Barea, & K. Haselwandter, (eds.), Birkhauser Verlag, Basel Switzerland, 281-296.

Alves, R.B.J., Boddey, M.R. & Urquiaga, S. (2003), "The Success of BNF in Soybean in Brazil", *Plant and Soil*, 252, Kluwer Academic Publishers, 1-9.

Amutha A.I. (2011), "The Growth Kinetics of Arachis Hypogaea L. Var. TMV-7 under the Inoculation of Biofertilizers With Reference To Physiological and Biochemical Studies", *PhD Thesis*, Department of Botany and Research Centre, Manonmaniam Sundaranar University, India.

Antoun, H., Beauchamp, C.J., Goussard, R., Chabot, R. & Lalande, R. (1998), "Potential of Rhizobium and Bradyrhizobium Species as Growth Promoting Rhizobacteria on non-legumes: Effect on Radishes (Raphanus sativus L.), *Plant and Soil*, 204, Kluwer Academic Publishers, 57-67.

Babalola, O.O. & Glick, B.R. (2012), "The Use of Microbial Inoculants in African Agriculture: Current Practice and Future Prospects", *Journal of Food, Agriculture and Environment*, 10(3&4), 540-549.

Banayo, N.P.M., Cruz, P.C.S., Aguilar, E.A. Badayos, R.B. & Haefele, S.M. (2012), "Evaluation of Biofertilizers in Irrigated Rice: Effects on Grain Yield at Different Fertilizer Rates", *Agriculture,* 2, 73-86.

BANR/NRC (2003), "Frontiers in Agricultural Research: Food, Health, Environment and Communities", Board on Agriculture and Natural Resources, National Research Council (BANR/NRC), Washington (DC), National Academics Press.

Belane, A.K. & Dakora, F.D. (2010), "Symbiotic N_2 Fixation in 30 Field-Grown Cowpea (*Vigna Unguiculata* L. Walp.) Genotypes in the Upper West Region of Ghana measured Using 15n Natural Abundance", *Biology and Fertility of Soils*, 46, 191-198.

Bhardwarj, D., Ansari, M.W., Sahoo, R.K. & Tuteja, N. (2014), "Biofertilizers Function as Key Player in Sustainable Agriculture by Improving Soil Fertility, Plant Tolerance and Crop Productivity", *Microbial Cell Factories*, 13: 66, 1-10.

Bhattacharyya, P., & Tandon, H.L.S. (2012), "Biofertilizer Handbook – Research – Production – Application", Fertilizer Development and Consultation Organization, New Delhi, India.

Boonkerd, N. (1991), "Inoculant Quality Control and Standards in Thailand", Report on the Expert Consultation on Legume Inoculant Production and Quality Control, Thompson, J.A. (ed.), FAO, Rome, 121-129.

Brahmaprakash, G.P. & Sahu, P.K. (2012), "Biofertilizers for Sustainability", *Journal of the Indian Institute of Science*, 92(1), 37-62.

Brenner, C. (1996), "Policy Options for Developing Countries: Getting Into the Agricultural Biotechnology Act?" Biotechnology and Development Monitor No. 29 http://www.biotech-monitor.nl/2906.htm Accessed: 14 April 2015

Caballero-Mellado, J., Carcano-Montiel, M.G. & Mascarua-Esparza, M.A. (1992), "Field Inoculation of Wheat (Triticum Aestivum) With Azospirillum Brasilense under Temperate Climate", *Symbiosis*, 13, 243–253.

Canadian Fertilizer Products Forum (2007), "Research Report Product Registration, Issues & Insights", Agriculture and Agri-Food Canada, http://www.cfpf-fcpf.ca Accessed: 02 March 2015.

Çakmakçi, R., Dönmez, F., Aydin, A. & Sahin, F. (2006), "Growth Promotion of Plants by Plant Growth-Promoting Rhizobacteria under Greenhouse and Two Different Field Soil Conditions", *Soil Biology and Biochemistry*, 38, Elsevier, 1482–1487.

Catroux, G. (1991), "Inoculant Quality Standards and Controls in France", In Expert Consultation on Legume Inoculant Production and Quality Control, Rome, 19-21 March, Thompson V.A. (ed.), FAO, Rome, 113-120.

Catroux, G., Hartmann, A. & Revellin, C. (2001), "Trends in Rhizobial Inoculant Production and Use", *Plant and Soil,* 230, Kluwer Academic Publishers, 21-30.

CFIA (2013), Industry notice – Fertilizer Regulations Amendments Enable Focus on Safety. Canadian Food Inspection Agency (CFIA). http://www.inspection.gc.ca. Accessed: 01 May 2015.

Chandler, D., Bailey, A.S., Tatchell, G.M., Davidson, G., Greaves, J. & Grant, W.P. (2011), "The Development, Regulation and Use of Pesticides for Integrated Pest Management", *Philosophical Transactions of the Royal Society B*, 366, the Royal Society Publishing, 1987–1998.

Chen, J. (2006), "The Combined use of Chemical and Organic Fertilizers and/ or Bio-fertilizer for Crop Growth and Soil Fertility", In Proceedings of the International Workshop on Sustained Management of the Soil Rhizosphere System for Efficient Crop Production and Fertilizer Use, Held 16-20 October, Bangkok, Thailand.

Chianu, J.N., Nkonya, E.M., Mairura, F.S., & Akinnifesi, F.K. (2011), "Biological Nitrogen Fixation and Socioeconomic Factors for Legume Production in Sub-Saharan Africa: A Review", *Agronomy for Sustainable Development,* 31(1), 139-154.

Choudhury, A.T.M.A. & Kennedy, I.R. (2004), "Prospects and Potentials for Systems of Biological Nitrogen Fixation in Sustainable Rice Production", *Biology and Fertility of Soils*, 39(4), 219-227.

Cocking, E.C. (2000), "Helping Plants Get More Nitrogen from the Air", European Review, 8(2), 193-200.

COMESA (2014), Fertilizer Harmonization Programme Launched, The Common Market for Eastern and Southern Africa (COMESA) 13 November 2014. http://www.comesa.int. Accessed: 10 March 2015.

Cong, P.T., Dung, T.D., Nguyen, T.H., Choudhury, A., Rose, M.T., Kecskes, M.L., Deaker, R. & Kennedy, I.R. (2011), "Effects of a Multistrain Biofertilizer and Phosphorus Rates on Nutrition and Grain Yield of Paddy Rice on a Sandy Soil in Southern Vietnam", *Journal of Plant Nutrition*, 34(7), 1058-1069.

Cordell, D., Drangert, J. & White, S. (2009), "The Story of Phosphorus: Global Food Security and Food For Thought. Global Environmental Change", 19(2), Elsevier, 292-305.

Coutinho, H.L., DeOliveira, V.M., & Moreira, F.M.S. (2000), "Systematics of Legume Nodule Nitrogen Fixing Bacteria", *Applied Microbial Systematics*, Springer Netherlands, 107–134.

Das, K. & Dang, R. (2010), "Influence of Biofertilizers on Stevioside Content in Stevia Rebaudiana grown in Acidic Soil Condition", *Archives of Applied Science Research*, 2(4), 44-49.

Desyane, H.K. & Wiyana, A. F. (2012), "Proposed Quality Improvement of Liquid Organic Fertilizers 'Herbafarm' to Meet National Standards in Indonesia", *The Indonesian Journal of Business Administration,* 1(6), 343-352.

Dhlamini, Z., Spillane, P., Moss, J.P., Ruane, J., Urquia, N. & Sonnino, A., (2005), "Status of Research and Application of Crop Biotechnologies in Developing Countries", FAO, Rome.

Direkvandi, S.N., Ansari, N.A. & Dehcordie, F.S. (2008), "Effects of Different Levels of Nitrogen Fertilizer with Two Types of Bio-fertilizer on Growth and Yield of Two Cultivars of Tomato (Lycopersicon esculentum Mill)", *Asian Journal of Plant Sciences*, 7(8), 757-761.

Dittoh, S., Omotesho, O., Belemvire, A., Akuriba, M. & Haider, K. (2012), "Improving the Effectiveness, Efficiency and Sustainability of Fertilizer Use in Sub-Saharan Africa", Briefing Paper No. 3. Global Development Network, Agriculture Policy Series.

Dobereiner, J., Urquiaga, S., & Boddey, R.M. (1995), "Alternatives for Nitrogen Nutrition of Crops in Tropical Agriculture", *Fertilizer Research*, 42, Kluwer Academic Publishers, 339–346.

Dutta, D. & Bandyopadhyay, P. (2009), "Performance of Chickpea (Cicer arietinum L.) To Application of

Phosphorus and Bio-Fertilizer in Laterite Soil", *Archives of Agronomy and Soil Science*, 55(2), 147-155.

Effiong, G.S. & Ibia, T.O. (2009), "Characteristics and Constraints of Some River Flood Plain Soils to Crop Production in Southeastern Nigeria", *Agricultural Journal*, 4(2), 103-108.

El-Nagdy, G.A., Dalia, M.A.N., Eman, A.E. & Gelan, S.A.EL. (2010), "Response of Flax Plant (Linum usitatissumum L) to Treatments with Mineral and Bio-fertilizers from Nitrogen and Phosphorus", *Journal of American science*, 6(10), 207-217.

Enti-Brown, S., Yeboah, P.O., Akoto-Bamford, S., Anim, A.K., Abole, H., Kpattah, L., Hanson, J.E.K., Ahiamadjie, H. & Gyamfi, E.T. (2012), "Quality Control Analysis of Imported Bio-fertilizers used in Ghana: the Macronutrients Perspective", Proceedings of the International Academy of Ecology and Environmental Sciences, IAEES, 2(1), 27-40.

European Fertilizer Manufacturers Association, (2000), "Phosphorus: Essential Element for Food Production", European Fertilizer Manufacturers Association (EFMA), Brussels.

Fairhurst, T. (ed.), (2012), "Handbook for Integrated Soil Fertility Management", Africa Soil Health Consortium, Nairobi (Kenya), CAB International.

Faranak, M.I., Isfahani, S.M., Besharati, H. & Tarigaleslami, M. (2013), "Yield and Concentration of Some Macro and Micro Nutrients of Cucumber as Influenced by Bio-fertilizers", *Annals of Biological Research*, 4(8), 61-67.

Gianinnazi, S. & Vosatka, M. (2004), "Inoculum of Arbuscular Mycorrhizal Fungi for Production Systems: Science Meets Business", *Canadian Journal of Botany*, 82(8), 1264-1271.

Giller, K.E. (2001), "Nitrogen Fixation in Tropical Cropping Systems", CABI Publishing, Wallingford, UK.

Graham, P.H. (1988), "Principles and Application of Soil Microbiology", 322–345.

Graham, P.H. & Vance, C.P. (2003), "Legumes: Importance and Constraints to Greater Use", *Plant Physiology*, 131(3), 872–877.

Graham, P.H., Hungria, M., & Tlusty, B. (2004), "Breeding For Better Nitrogen Fixation in Grain Legumes: Where Do the Rhizobia Fit In?" *Crop Management,* doi: 10.1094/CM-2004-0301-02-RV

Gharib, A.A., Shahen, M.M. & Ragab, A.A. (2009), "Influence of Rhizobium Inoculation Combined with Azotobacter Chroococcum and Bacillus Megatarium Var Phosphaticum on Growth, Nodulation, Yield and Quality of Two Snap Bean (Phaseolus vulgaris L.) Cultivars", In 4th Conference on Recent Technologies in Agriculture, Held 3-5th November, Cairo, Egypt, 650-662.

Ghosh, N. (2003), "Promoting Bio-fertilizers in Indian Agriculture", Institute of Economic Growth University Enclave. India. http://www.ipni.net. Accessed 25 April 2015)

Guo, Z., Koo, J. & Wood, S. (2009), "Fertilizer Profitability in East Africa: A Spatially Explicit Policy Analysis", In Conference Proceedings, International Association of Agricultural Economists Conference, Held August 16-22, Beijing, China (No. 51710), International Association of Agricultural Economists.

Gupta, R.P., Anu, K., & Shammi, K. (2007), "Bioinoculants*:* A Step towards Sustainable Agriculture, New India Publishing.

Gyaneshwar, P., Naresh, K.G., Parekh, L.J. & Poole, P.S. (2002), "Role of Soil Microorganisms in Improving P Nutrition of Plants, *Plant and Soil*, 245, 83–93.

Harman, G.E., Obregon, M.A., Samuels, G.J. & Lorrito, M. (2010), "Changing Models for Commercialization and Implementation of Biocontrol in the Developing and Developed World", *Plant Disease: an International Journal of Applied Plant Pathology*, 94(8), 928-939.

Hashem, M.A. (2001), "Problems and Prospects of Cyanobacterial Biofertilizer for Rice Cultivation", *Australian Journal of Plant Physiology*, 28(9), 881– 888.

Hedge, D.M., Dwivedi, B.S. & Babu, S.N.S. (1999), "Biofertilizers for Cereal Production in India: A Review", *India Journal of Agricultural Sciences*, 69(2), 73-83.

Herridge, D., Gemell, G. & Hartley, E. (2002), "Legume Inoculants and Quality Control. In: Inoculants and Nitrogen Fixation of Legumes in Vietnam", ACIAR Proceedings, 109e, 105-115.

Herridge, D.F., Peoples, M.B., Boddey, R.M. (2008), "Global Inputs of Biological Nitrogen Fixation into Agricultural Systems", *Plant and Soil*, 311(1-2), 1-18.

Howieson, J. & Ballard, R. (2004), "Optimizing the Legume Symbiosis in Stressful and Competitive Environments within Southern Australia—Some Contemporary Thoughts", *Soil Biology and Biochemistry*, 36(8), 1261-1273.

Hungria, M. & Campo, R.J. (2007), "Inoculantes Microbianos: Situacio´n en Brasil", M.L., Izaguirre-Mayoral, C., Labandera, J., Sanjuan (eds.) *Biofertilizantes en Iberoamerica*: Visio´nte´cnica, cienti´fica yempresarial, Denad Internacional, Montevideo, 1, 22–31.

Hungria, M., Franchini, J.C., Campo, R.J., Crispino, C.C., Moraes, J.Z., Sibaldelli, R.N.R., Mendes, I.C. & Arihara, J. (2006), "Nitrogen Nutrition of Soybean in Brazil: Contributions of Biological N_2 Fixation and Nitrogen Fertilizer to Grain Yield", *Canadian Journal of Plant Science*, 86(4) 927-939.

Ishizuka, J. (1992), "Trends in Biological Nitrogen Fixation Research and Application", *Plant and Soil,* 141(1-2), 197–207.

Ivanova, E., Teunou, E. & Poncelet, D. (2005), "Aligate Based Macrocapsules as Inoculants Carriers for Production of Nitrogen Bio-fertilizers", Proceedings of the Balkan Scientific Conference of Biology in Plovdiv (Bulgaria), Held 19-21 May 2005, 90-108.

Javaid, A. & Mahmood, N. (2010), "Growth, Nodulation and Yield Response of Soybean to Biofertilizers and Organic Manures", *Pakistan Journal of Botany,* 42(2), 863-871.

Jefwa, J.M., Pypers, P., Jemo, M., Thuita, M., Mutegi, E., Laditi, M.A., Faye, A., Kavoo, A., Munyahali, W., Herrmann, L., Atieno, M., Okalebo, J.R., Yusuf, A., Ibrahim, A., Ndung'u-Magiroi, K.W., Asrat, A., Muletta, D., Ncho, C., Kamaa, M., and Lesueur, D. (2014), "Do Commercial Biological and Chemical Products Increase Crop Yields and Economic Returns Under Smallholder Farmer Conditions?", In Challenges and opportunities for agricultural intensification of the humid highland systems of sub-Saharan Africa, B., Vanlauwe, P., van Asten, and G., Blomme, (eds.), Springer International Publishing, Switzerland, 81-96.

Jetiyanon, K. & Pliabanchang, P. (2011), "Potential of *Bacillus cereus Strain RS87* for Partial Replacement of Chemical Fertilizers in the Production of Thai Rice Cultivars", *Journal of Science, Food and Agriculture*, 92(5), 1080-1085.

Jha, M.N. & Prasad, A.N. (2006), "Efficacy of New Inexpensive Cyanobacterial Biofertilizer Including its Shelf Life", *World Journal of Microbiology and Biotechnology,* 22(1), 73-79.

Jha, M.N., Kumar, P. & Chourasia, S.K. (2012), "Hope, Hype and Reality of Biofertilizer", *Fertilizer Technology*, 121, 448-480.

Jilani, G., Akram, A., Ali, R.M., Hafeez, F.Y., Shamsi, I.H., Chaudhry, A.N. & Chaudhry, A.G. (2007), "Enhancing Crop Growth, Nutrients Availability, Economics and Beneficial Rhizosphere Microflora through Organic and Biofertilizers", *Annals of Microbio*logy, 57(2), 177-184.

Kannaiyan, S. (2003), "Inoculant Production in Developing Countries-Problems, Potentials and Success", In Maximising the use of Biological Nitrogen Fixation in Agriculture, G., Hardarson & W.J., Broughton, (eds.), *Developments in Plant and Soil Sciences,* 99, Kluwer Academic Publishers, 187-198.

Karanja, N., Freire, J., Gueye, M. & DaSilva, E. (2000), "MIRCEN Networking: Capacity Building and BNF Technology Transfer in Africa and Latin America", AgBiotechNet, 2 March, ABN 043.

Khan, A.A., Jilani, G., Akhtar, M.S., Navqi, S.M.S. & Rasheed, M. (2009), "Phosphorus Solubilizing Bacteria: Occurrence, Mechanisms and their Role in Crop Production", *Journal of Agriculture and Biological Sciences*, 1(1), 48-58.

Khokhar, S.N. (2012), "Crop Inoculants: An Underexplored Potential in Agriculture", *Pakistan Journal of Agricultural Resources*, 25(1), 83-90.

Kumar, V. (2014), "Characterization, Bio-Formulation Development and Shelf-Life Studies of Locally Isolated Bio-fertilizer Strains", *Octa Journal of Environmental Research*, 2(1), 32-37.

Lucy, M., Reed, E. & Glick, B.R. (2004), "Applications of Free Living Plant Growth-Promoting Rhizobacteria", Antonie Van Leeuwenhoek, 86(1), Kluwer Academic Publishers, 1–25.

Mahdi, S.S., Hassan, G.I., Samoon, S.A., Rather, H.A., Dar, S.A. & Zehra, B. (2010), "Bio-fertilizers in Organic Agriculture", *Journal of Phytology*, 2(10), 42-54.

Majengo, C.O., Okalebo, J.R., Lesueur, D., Pypers, P., Ng'etich, W., Mutegi, E., Mburu M.W. & Musyoki, M. (2011), "Interaction between Nitrogen and Phosphorus Microbial Inoculants on Soybean Production in Bungoma, Kenya", *African Crop Science Conference Proceedings*, 10, 121 – 123.

Malik, A.A., Sanghmitra, S. & Javed, A. (2011), "Chemical vs. Organic Cultivation of Medicinal and Aromatic Plants: The Choice is clear", *International Journal of Medicinal and Aromatic Plants*, 1(1), 5-13.

Mandal, B., Vlek, P.L.G. & Mandal, L.N. (1999), "Beneficial Effects of Blue-Green Algae and Azolla, Excluding Supplying Nitrogen, on Wetlands Rice Fields: A Review", *Biology and Fertility of Soils*, 28, 329-342.

Mandal, A., Patra, A. K., Singh, D., Swarup, A., Purakayastha, T. J. & Masto, R. E. (2009), "Effects of Long-Term Organic and Chemical Fertilization on N and P in Wheat Plants and in Soil During Crop Growth", *Agrochimica,* 53(2), 79-91.

Mapfumo, P. (2011), "Comparative Analysis of the Current and Potential Role of Legumes in Integrated Soil Fertility Management in Southern Africa", http://www.researchgate.net. Accessed: 20 Mar 2015.

Masso, C., Jefwa, J.M., Jemo, M., Thuita, M., Tarus, D., Vanlauwe, B. (2014), "Impact of Inadequate Regulatory Frameworks on the Adoption of Bio-Fertilizers (E.G. PGPR) Technologies: A Case Study of sub-Saharan Africa", In Recent Advances in Biofertilizers and Biofungicides (PGPR) For Sustainable Agriculture, S.R. Munagala et al. (ed.), Newcastle upon Tyne (UK): Cambridge Scholars Publishing, 258-268.

Matiru, V.N. & Dakora, F.D. (2004), "Potential Use of Rhizobial Bacteria as Promoters of Plant Growth for

Increased Yield in Landraces of African Cereal Crops", *African Journal of Biotechnology,* 3, 1–7.

Mazid, M. & Khan, T.A. (2014), "Future of Bio-fertilizers in Indian Agriculture: An Overview", *International Journal of Agricultural and Food Research*, 3, 10-23.

Mehrvarz, S., Chaichi, M.R. & Alikhani, H.A. (2008), "Effects of Phosphate Solubilizing Microorganisms and Phosphorus Chemical Fertilizer on Yield and Yield Components of Barley (Hordeum vulgare L.)", *American-Eurasian Journal of Agriculture and Environmental Sciences*, 3(6), 822-828.

Mia, M.A.B. & Shamsuddin, Z. H. (2010), "Rhizobium as a Crop Enhancer and Biofertilizer for Increased Cereal Production", *African Journal of Biotechnology-Academic Journals*, 9(37), 6001-6009.

Mishra, P. & Dash, D. (2014), "Rejuvenation of Bio-fertilizers for Sustainable Agriculture and Economic Development", *Consilience: the Journal of Sustainable Development,* 11(1), 41-61.

Mondal, T., Datta, J.K. & Mondal, N.K. (2015), "An Alternative Eco-Friendly Approach for Sustainable Crop Production With The Use of Indigenous Inputs Under Old Alluvial Soil Zone Of Burdwan, West Bengal, India", *Archives of Agronomy and Soil Science*, 61(1), 55-72.

Monem, M.A.S.A., Khalifa, H.E., Beider, M., El Ghandour, I.A. & Galal, Y.G.M. (2001), "Using Biofertilizers for Maize Production: Response and Economic Return under Different Irrigation Treatments", *Journal of Sustainable Agriculture*, 19(2), 41-48.

Moreno-Sarmiento, N., Moreno-Rodriguez, L.F. & Uribe, D. (2007), "Biofertilizantes para la agricultura en Colombia", Izaguirre-Mayoral M.L., Labandera-C., Sanjuan J. (eds.) *Biofertilizantes en Iberoamerica*: Visionte´ cnica, cienti´fica y empresarial, Denad Internacional, Montevideo, 1, 38–45.

Motsara, M.R., Bhattacharya, P.B. & Srivastava, B. (1995), "Sources of Nitrogen and the Importance of Biofertilizers P.6", Biofertilizer Technology, Marketing and Usage, Fertilizer Development and Consultation Organization, New Delhi, India.

Mpepereki, S., Javaheri, F., Davis, P. and Giller, K.E. (2000), "Soybeans and Sustainable Agriculture. Promiscuous Soybeans in Southern Africa", *Field Crops Research*, 65,137- 149.

Mugabe, J. (1994), "Research on Biofertilizers: Kenya, Uganda and Tanzania", Biotechnology and Development Monitor, No.18, 9-10.

Mulas, D., Diaz-Alcantara, C.A., Mulas, R., Marcano, I., Barquero M., Serrano, P. & Gonzalez-Andres, F. (2013), "Inoculants Based in Autochthonous Microorganisms: a Strategy to Optimize Agronomic Performance of Biofertilizers", In Beneficial Plant-Microbial Interactions: Ecology and Applications, M.B.R. Gonzales & J. Gonzales-Lopez, (eds.), 300-328.

Mullen, M.D., Isreal, D.W. & Wollum, A.G. (1988), "Effects of *Bradyrhizobium Japonicum* on *Glycine Max*. Phosphorus Nutrition on Nodulation and Dinitrogen Fixation", *Applied and Environmental Microbiology,* 54, 2387–92.

Mulongoy K., Gianinazzi S., Roger P.A. & Dommergues Y. (1992), "Bio-fertilizers: Agronomic and Environmental Impacts and Economics", In Biotechnology: Economic and Social Aspects: Issues for Developing Countries, E.J. DaSilva, C. Ratledge and A. Sasson (eds.), Cambridge University Press, 55-69.

Naseriad, H., Soleymanifard, A. & Naseri, R. (2011), "Effect of Integrated Application of Biofertilizers on Grain Yield, Yield Components and Associated Traits of Maize Cultivars", *American-Eurasian Journal of Agriculture and Environmental Sciences*, 10(2), 271-277.

Nguyen, V.S. (2006), "The Production and Application of Bio-fertilizers in Vietnam", In Proceedings of International Workshop on Sustained Management of the Soil Rhizosphere System for Efficient Crop Production and Fertilizer Use, Held 16-20 October, Thailand.

Nicolas, M.F., Hungria, M. & Arias, C.A.A. (2006), "Identification of Quantitative Trait Loci Controlling Nodulation and Shoot Mass in Progenies from Two Brazilian Soybean Cultivars", *Field Crops Research*, 95, 355-366.

Njira, K.O.W. (2013), "Microbial Contributions in Alleviating Decline in Soil Fertility", *British Microbiology Research Journal*, 3(4), 724-742.

Nwaobiala, C.U. & Ogbonna, M.O. (2014), "Adoption Determinants and Profitability Analysis of Okra Farming in Aninri Local Government Area (LGA) of Enugu State, Nigeria", *Discourse Journal of Agriculture and Food Sciences*, 2(1), 1-10.

Nziguheba, G., Palm, C.A., Berhe, T., Denning, G., Dick, A., Diouf, O., Diru, W., Flor, R., Frimpong, F., Harawa, R., Kaya, B., Manumbu, E., McArthur, J., Mutuo, P., Ndiaye, M., Miang, A., Nkhoma, P., Nyadzi, G., Sachs, J., Sullivan, C., Teklu, G., Tobe, L., Sanchez, P. (2010), "The African Green Revolution: Results From The Millenium Villages Project", *Advances in Agronomy*, 109, 75-115.

Ochieng, J.R.A. (2015), "Towards a Regulatory Framework for Increased and Sustainable Use of Bio-fertilizers in Kenya", *MA Thesis*, Centre for Advanced Studies in Environmental Law and Policy (CASELAP), University of Nairobi.

Odame, H. (1997), "Biofertilizer in Kenya. Research, Production and Extension Dilemmas", Biotechnology and

Development Monitor, 30, 20-23.

Okon, Y. & Labandera-Gonzalez, C.A. (1994), "Agronomic Applications of *Azospirillum*: An Evaluation of 20 Years Worldwide Field Inoculation", *Soil Biology and Biochemistry,* 26, 1591-1601.

Olivares, J., Bedmar, E.J. & Sanjuan, J. (2013), "Biological Nitrogen Fixation in the Context of Global Change", *Molecular Plant Microbe Interactions,* 26(5), the American Phytopathological Society 486-494.

Ozturk, A., Caglar, O. & Sahin, F. (2003), "Yield Response of Wheat and Barley to Inoculation of Plant Growth Promoting Rhizobacteria at Various Levels of Nitrogen Fertilization", *Journal of Plant Nutrition and Soil Science*, 166, 262-266.

Panwar, A. S., Raiyan, J.S. & Verma, V. S. (2000), "Yield and Quality of Radish (Raphanus Sativus L) Seed as Affected by Fertility Levels and Bio-Fertilizers", *Indian Journal of Agronomy*, 45(4), 822-826.

Peoples, M. B., Herridge, D.F. & Ladha, J.K. (1995), "Biological Nitrogen Fixation: An Efficient Source of Nitrogen for Sustainable Agricultural Production", *Plant and Soil*, 174, 3-28.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D. & Seidel, R. (2005), "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems", American Institute of Biological Sciences, 55(7), Oxford University Press, 573-582.

Pradhan, R., Amin, N., Haque, E., Hossain, M. & Sarwar, G. (2013), "Involvement of Private Sector for Commercialization of Bradyrhizobium Technology: Impact on Soybean Production in Bangladesh", Commercialization of Bradyrhizobium- SATNET, http://www.satnetasia.org. Accessed: 6 April 2015

Pray, C.E. & Nagarajan, L. (2012), "Innovation and Research by Private Agribusiness in India", Discussion Paper, IFPRI, International Food Policy Research Institute*,* 1181.

Qureshi, M.A., Ahmad, M.J., Naveed, M., Iqbal, A., Akhtar, N. & Niazi, K.H. (2009), "Co-inoculation with Mesorhizobium ciceri and Azotobacter chroococcum for Improving Growth, Nodulation and Yield of Chickpea (Cicer arietimum L.)", *Soil and Environment*, 28, 124-129.

Rabindra, R.J. & Grzywacz, D. (2010), "Use and Regulation of Microbial Pesticides in Representative Jurisdictions Worldwide-India", T., Kabaluk, A., Svircev, M., Goettel, S.G., Woo (eds.), IOBC Global, 12-17.

Raja, N. (2013), "Biopesticides and Biofertilizers: Ecofriendly Sources for Sustainable Agriculture", *Journal of Biofertilizers and Biopesticides*, 4: e112. doi:10.4172/2155-6202.1000e112.

Ramakrishnan, K. & Bhuvaneswari, G. (2014), "Effect of Inoculation of AM Fungi and Beneficial Microorganisms on Growth and Nutrient Uptake of Eleusine corocana (L.) Gaertn. (Finger Millet)", *International Letters of Natural Sciences,* 8(2), 59-69.

Ramesh, P., Singh, N. & Suba Rao, A. (2005), "Organic Farming: Its Relevance to the Indian Context", *Current Science*, 88(4), 561-568.

Ravensberg, W.J. (2013), "Commercialization of Microbes: Present Situation and Future Prospects", B. Lugtenberg (ed.), *Principles of Plant-Microbe Interactions,* Springer International Publishing, Switzerland, *309-317.*

Rengel, Z. (2002), "Breeding for Better Symbiosis", *Plant and soil,* 245, 147–*1*62.

Roy, R.N., Finck, A., Blair, G.J. & Tandon H.L.S. (2006), "Plant Nutrition for Food Security: A Guide for Integrated Nutrient Management", FAO Fertilizer and Plant Nutrition Bulletin 16, FAO, Rome.

Sahin, F., Çakmakçi, R. & Kantar, F. (2004), "Sugar Beet and Barley Yields in Relation to Inoculation with N-Fixing and Phosphate Solubilizing Bacteria", *Plant and Soil,* 265, 123–129.

Sanchez, P.A. (2002), "Soil Fertility and Hunger in Africa", Science Compass*,* Policy Forum*,* 295, 2019-2020.

Santi, C., Bogusz, D. & Franche, C. (2013), "Biological Nitrogen Fixation in Non-Legume Plants", *Annals of Botany,* Oxford University Press*,* 111, 743-767.

Schulte-Geldermann, E. (2013), "Tackling Low Potato Yields in Eastern Africa: An Overview of Constraints and Potential Strategies", In Seed Potato Tuber Production and Dissemination, Experiences, Challenges and Prospects, G., Woldegiorgis, S., Schulz & B., Berihun (eds.), National Workshop on Seed Potato Tuber Production and Dissemination. Bahir Dar (Ethiopia), Held 12-14 Mar 2012, Ethiopia, Ethiopian Institute of Agricultural Research (EIAR); Amhara Regional Agricultural Research Institute (ARARI); International Potato Center, 72-80.

Shaheen, A.M., Fatma, A. R., Sawan, M.O. & Ghoname, A.A. (2007), "The Integrated Use of Bio-inoculants and Chemical Nitrogen Fertilizer on Growth, Yield and Nutritive Value of Two Okra (Abelmoschus Esculentus L.) Cultivars", *Australian Journal of Basic and Applied Sciences*, 1, 307-312.

Sheahan, M. & Barrett, C.B. (2014), "Understanding the Agricultural Input Landscape in sub-Saharan Africa – Recent Plot, Household, and Community-Level Evidence", World Bank Group, Africa region, Office of the Chief Economist.

Simanungkalit, R.D.M., Roughley, R.J., Hastuti, R.D., Indrasumunar, A. & Pratiwi, E. (1996), "Inoculation of Soybean with Selected Strains of Bradyrhizobium Japonicum Can Increase Yield on Acid Soils in Indonesia", *Soil Biology and Biochemistry*, 28, 257-259.

Simiyu, N.S.W., Tarus, D., Watiti, J. & Nang'ayo, F. (2013), "Effective Regulation of Bio-Fertilizers and Bio-Pesticides: A Potential Avenue to Increase Agricultural Productivity", Policy Series, COMPRO II, International Institute of Tropical Agriculture, 1.

Singleton, P. W., Bohlool, B. B., & Nakao, P. L. (1992), "Legume Response to Rhizobial Inoculation in the Tropics: Myths and Realities", In Myths and Science of Soils of the Tropics, R., Lal & P. A., Sanchez (eds.), Soil Science Society of America and American Society of Agronomy Special Publication, No. 29, 135-155.

Sinha, R.K. (1998), "Embarking on the Second Green Revolution for Sustainable Agriculture in India: A Judiciuos Mix of Traditional Wisdom and Modern Knowledge in Ecological Farming", *Journal of Agricultural and Environmental Ethics*, 10, 183-197.

Sirmamata, T. (2013), "Tropical Bio-resources To Support Biofertilizer Industry and Sustainable Agriculture in Indonesia", Paper for International Seminar on Tropical Bio-resources for Sustainable Bio-industry 2013; from Basic Research to Industry, Held 30 – 31st October 2013, in West and East Hall –ITB-Bandung-Indonesia.

Sivasakthivelan, P. & Saranraj, P. (2013), "Azospirillum and its Formulations: A Review", *International Journal of Microbiological Research*, 4(3), IDOSI Publications, 275-287.

Smaling, E., Toure, M., de Ridder, N., Sanginga, N., & Breman, H. (2006), "Fertilizer Use and the Environment in Africa: Friend or Foes*?"* Background Paper, Prepared for the Africa Fertilizer Summit, Abuja.

Smith, R.S. (1992), "Legume Inoculant Formulation and Application", *Canadian Journal of Microbiology*, 38, 485-492.

Spencer, D., James, E.K., Ellis, G.J., Shaw, J.E., & Sprent, J.I. (1994), "Interactions between Rhizobia and Potato Tissue", *Journal of Experimental Botany*, 45, 1475–1482.

Stephens, J.H.G. & Rask, H.M. (2000), "Inoculant Production and Formulation", *Field Crops Research*, 65, 249-258.

Strijdom, B.W. (1998), "South African Studies on Biological Nitrogen Fixing Systems and the Exploitation of the Nodule Bacterium-Legume Symbiosis", *South African Journal of Science*, 94, 11-23.

Suja, G. (2008), "Strategies for Organic Production of Tropical Tuber Crops", In Organic Farming in Rain fed Agriculture: Opportunities and Constraints, B.Venkateswarlu, S.S.Balloli & Y.S. Ramakrishna (eds.), Central Research Institute for Dryland Agriculture, Hyderabad, 135-143.

Sundara, B., Natarajan, V. & Hari, K. (2002), "Influence of Phosphorus Solubilizing Bacteria on the Changes in Soil Available Phosphorus and Sugarcane Yields", *Field Crops Research*, 77, 43-49.

Sutton, M.A., Bleeker, A., Howard, C.M., Bekunda, M., Grizzetti, B., de Vries, W., van Grinsven, H.J.M., Abrol, Y.P., Adhya, T.K., Billen, G., Davidson, E.A, Datta, A., Diaz, R., Erisman, J.W., Liu, X.J., Oenema, O., Palm, C., Raghuram, N., Reis, S., Scholz, R.W., Sims, T., Westhoek, H. & Zhang, F.S., (2013), "Our Nutrient World: The Challenge to Produce More Food and Energy With Less Pollution", Centre for Ecology and Hydrology (CEH), Edinburgh, UK.

Tan, G.H., Nordin, M.S., Kert, T.L., Napsiah, A.B. & Jeffrey, L.S.H. (2009), "Isolation of Beneficial Microbes from Bio-fertilizer Products", *Journal of Tropical Agriculture and Food Science*, 37(1), 103-109.

Tarus, D., Ikerra, S., Masso, C. & Watiti, J. (2014), "Effective Regulation of Bio-fertilizers in Tanzania - Investing in Functional Institutional Frameworks", COMPRO II Policy Brief, COMPRO Policy Series, No. 3.

Thompson, J.A. (1991), "Legume Inoculant Production and Quality Control", In Expert Consultation on Legume Inoculant Production and Quality Control, V.A., Thompson (ed.), FAO, Rome, 113-120

Tiwari, P., Adholeya, A., Prakash, A., & Arora, D.K. (2004), "Commercialization of Arbuscular Mycorrhizal Biofertilizer", D.K., Arora, (ed.), *Fungal Biotechnology in Agricultural, Food, and Environmental Applications,* 21, 195-203.

Tiwari, V.N. (2005), "Bio-Fertilizers Facts, Prospectives and Future Strategy with Reference to Organic Farming", *Vegetos,* 18(1&2), 151-159.

Ullmann, W.J., Kirchman, D.L., Welch, S.A. & Vandevivere, P. (1996), "Laboratory Evidence for Microbially Mediated Silicate Mineral Dissolution in Nature", *Chemical Geology,* 132, 11–17.

Uribe, D., Sanchez-Nieves, J. & Vanegas, J. (2010), "Role of Microbial Bio-fertilizers in the Development of a Sustainable Agriculture in the Tropics", P. Dion (ed.), *Soil Biology and Agriculture in the Tropics,* 21, 235-250.

USAID, (2012), "Building an Enabling Environment for Fertilizer Sector Growth", Policy Brief No. 3, United States Agency for International Development *(*USAID*).*

Valadabadi, S.A. & Farahani, H.A. (2011), "Investigations of Biofertilizers Influence on Quantity and Quality Characteristics in *Nigella sativa L.*", *Journal of Horticulture and Forestry*, 3(3), 88-92.

Vance, C.P. (2001), "Symbiotic Nitrogen Fixation and Phosphorus Acquisition: Plant Nutrition in a World of Declining Renewable Resources", *Plant Physiology*, 127, 390–397.

Venkataraman, G.S. & Tilak, K.V.B.R. (1990), "Biofertilizers in Sustainable Agriculture", V. Kumar G. C. Shrotriya & S.V. Kaore, (eds.), *Soil Fertility and Fertilizer Use*, 4, 137-148.

Waddington, S., Sakala, D., Mekuria, M. (2004), "Progress in Lifting Soil Fertility in Southern Africa", In Proceedings of the 4th International Crop Science Congress, Held 26 Sep – 1 Oct 2014, Bisbane, Australia.

Wahab, S. (2009), "Biotechnological Approaches in the Management of Plant Pests, Diseases and Weeds for Sustainable Agriculture", *Journal of Biopesticides*, 2(2), 115-134.

Wang, H., Shen, L., Li-mei, Z., Ji-zong, Z., Tia-nzi, R., Bin-quan, F. & Hong-bin, L. (2014), "Preparation and Utilization of Phosphate Bio-fertilizers Using Agricultural Waste", *Journal of Integrative Agriculture*, 14(1), 158-167.

Webster, G., Gough, C., Vasse, J., Batchelor, C.A., O'Callaghan, K.J., Kthari, S.L., Davey, M. R., Denarie, J. & Cocking, E.C. (1997), "Interactions of Rhizobia With Rice and Wheat. *Plant and Soil*, 194 (1-2), 115-122.

Wolf, B. (1999), "The Fertile Triangle: The Interrelationship of Air, Water, and Nutrients In Maximizing Soil Productivity", The Haworth Press Inc., United States of America.

Woomer, P.L., Huising, J., Giller, K.E. (2014), "N2Africa Final Report of the First Phase 2009-2013", 138.

Woomer, P.L., Palm, C.A., Qureshi, J.N., Kotto-Same, J., (1997), "Carbon Sequestration and Organic Resources Management in African Smallholder Agriculture", In Management of Carbon Sequestration in Soil, R., Lal, J.M., Kimble, R.F., Follett & B.A., Stewart, (eds.), CRS Press, Boca Raton, FL., 153-171.

Yanni, Y.G., Rizk, R.Y., El-Fattah, F.K.A., Squartini, A., Corich, V., Giacomini A., de Bruijn, F, Rademaker, J., Maya-Fores, J., Ostrom, P., VegaHernandez, M., Hollingsworth, R.I., Martinez-Molina, E., Mateos, P.,Velaquez, E., Woperis, J., Triplett, E., Umali-Garcia, M., Anarna, J.A., Rolfe, B.G., Ladha, J.K., Hill, J., Mujoo, R., Ng, P.K. & Dazzo, F.B. (2001), "The Beneficial Plant-Growth Promoting Association of *Rhizobium Leguminosarum* Bv. *Trifolii* With Rice Roots", *Australian Journal of Plant Physiology*, 28,845-870.

Yasari, E. & Patwardhan, A.M. (2007), "Effects of (Azotobacter and Azospirillum) Inoculants and Chemical Fertilizers on Growth and Productivity of Canola (Brassica napus L.)", *Asian Journal of Plant Sciences*, Asian Network for Scientific Information, 6(1), 77-82.

Zaidi, A., Khan, M.S., Ahemad, M., Oves, M. & Wani, P.A. (2009), "Recent Advances in Plant Growth Promotion by Phosphate Solubilizing Microbes", M.S. Khan, A. Zaidi & J. Musarrat (eds.), *Microbial Strategies for Crop Improvement*, Springer-Verlag, Berlin Heidelberg, 23-50.

Zaki, M.F., Abdelhafeez, A.A.M. & El-Dewiny, C.Y. (2010), "Influence of Applying Phosphate Bio-fertilizers and Different Levels of Phosphorus Sources on the Productivity, Quality and Chemical Composition, of Sweet Fennel (Foeniculum Vulgare Mill.)", *Australian Journal of Basic and Applied Sciences,* 4(2), 334-347.

Zotarelli, L. (2000), "Balanço de Nitrogênio na Rotação de Culturas em Sistemas de Plantio Direto E Convencional na Região de Londrina", *PhD. Thesis*, PR. Universidade Federal Rural do Rio de Janeiro, Seropédica, Brazil.