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BIOFERTILIZER IN PROMOTING SUSTAINABLE AGRICULTURE FOR FOOD SAFETY AND SECURITY: A REVIEW

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ABSTRACT

Agriculture has an important role in human life worldwide. This is due to the fact that human or living creatures required agriculture for their foods and stability eco-systems. But, the demand for foods is different depending on the dietary trend required for each region around the world. Statistic data shows that approximately 795 million people are dying due to limited amounts of healthy foods daily which lead to unhealthy life-style that result in inducing motility. Thus, sustainable agriculture was introduced to reduce this limitation. However, despite good intentions in supplying an adequate amount of healthy foods worldwide, there is a question raising the issue of food safety and security from sustainable agriculture. This is due to the concern of chemical fertilization that is fully utilized by farmers in agriculture that may render supplementation of unhealthy food chains to the community. Biofertilizer was proposed to replace the chemical fertilizer at the same time promoting good practice of sustainable agriculture. Nonetheless, biofertilizer is a new technology that requires a good explanation especially for the farmer who is only familiar with conventional methods for their land farming. Therefore, in this review biofertilizer will be more focused and detailed information regarding its benefits and limitations will be discussed. In addition, the market demand for biofertilizers worldwide is also reviewed for its potential in sustaining economic growth. Food safety and security influence by biofertilizer was also investigated.

Keywords: Biofertilizer; Sustainable agriculture; Food safety; Food security

1.0 INTRODUCTION

Agriculture is a very important sector in the world. The main function of agriculture is to supply food to humans to ensure a stable and healthy ecosystem. Normally the food demand depends on dietary trends and also to alleviate poverty issues. Agriculture potentially has become a new source for energy such as biodiesel, biogas and bio-fuel which are derived from plants. Renewable energy resulting from plants able to reduce and overcome most of the problems related to depletion of fossil fuel energy [1-3]. In this study, biofertilizers are reviewed and detailed information regarding their potential usage and limitations are also discussed. The market demand for biofertilizer worldwide was also investigated especially for its potential in nourishing economic growth. Food safety and security that are influenced by biofertilizers are also explained.

1.1 The Statistic of World Hunger Issues

Recently about one over nine people in the world, which is equivalent to 795 million people are dying for not having healthy food or leading a healthy-active lifestyle; where starvation and undernourishment are failure factors that influence dying. Undernourished can be defined as an insufficient amount of essential food required to grow and promote a healthy lifestyle.

Table 1 The percentage of prevalence of undernourishment issues in the world from 1990 to recent [4].

	1990-92	2014-16
World	18.6	10.8
Developed countries	<5.0	<5.0
Developing countries	23.3	12.9
Africa	27.6	19.8
Asia	23.6	12.1
Latin America and the Caribbean	14.7	5.5
Oceania	15.7	14.2

The percentage of undernourished decreased from the 1990's to 2016 and about 12.9 percent of people from developing countries are undernourished. Meanwhile, the Sub-Saharan Africa region gives the highest population for undernourished issues compared with other regions in which every 1 person from 4 is identified as hunger [4].

In Africa, Ethiopia has the highest undernourishment issue, followed by Nigeria and Tanzania [4]. Based on Non-Governmental Organization (NGO) statistics, the most impact factor causing starvation and undernourishment issues in Africa is poverty. In 2008, 47 percent of Sub-Saharan Africans spent $1.25 for daily needs, thus proving that most of them are having insufficient money to purchase enough food [5]. Besides that, the challenging environmental conditions due to human activity such as over exploitation and deforestation for living, firewood and farming activity lead to other problems like desertification, a land process from fertile to becoming desert due to drought, deforestation and inappropriate agriculture activity. Other natural factors are drought and water shortage issues which limit their agricultural activity, thus reduce economic growth at African region [6-8].

1.2 World Hunger Issues and Impact on The Agricultural Sector

Due to malnutrition issues, 1 over 6 from 100 million children in the developing countries were classified as underweight [9] and 45 percent of deaths among the children under 5 years old caused by poor nutrient consumption in 3.1 million population [10]. Despite economic growth, agricultural trends had been influenced by this phenomena to meet food demand in the world, indirectly overcoming undernourishment as well as food security issues.

Land is necessary for sustainable agricultural development, essential ecosystem functions also as a solution for food security issues. About 12 percent of land in the world's area is reserved for plantation or agricultural activity [4]. According to figure 1, a nutrient consumption for elements such as sodium, potassium and phosphorus were gradually and continuously increased since 1960 until 2011 for China and India and in some study, it is reported the findings of China has adequate amount of food nutrient supply since 1965 to 2018, meanwhile Oita et al., 2020 also reported that China, India and Japan also has great nutrient supply since 1961 to 2013, respectively [11-13].

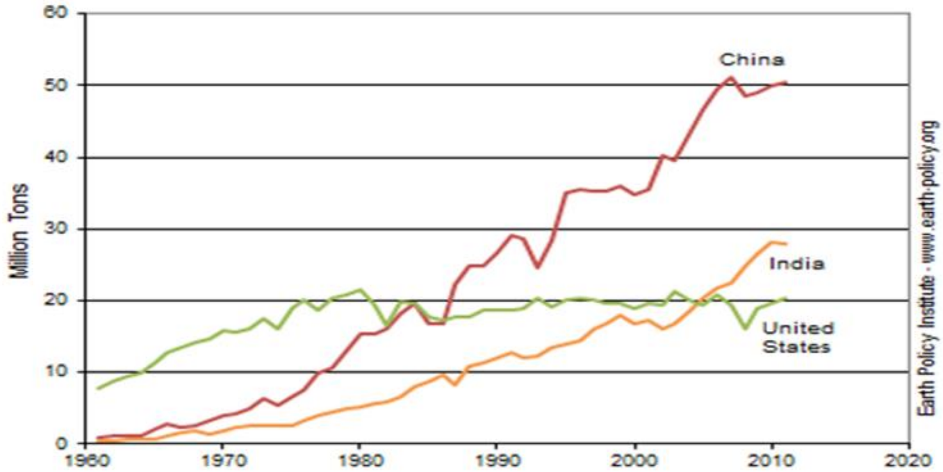

Figure 1 Fertilizer world trend for China, India and United State from 1960-2011 [11].

The main function of fertilizer is as a supplement or replacing a nutrient lost from arable land, thus to maintain soil productivity which indirectly improves crops production. It normally occurs in urbanized areas or high crops production in which the land had been used excessively and lead to further Nitrogen loss from soil [11]. Meanwhile, in the rural agricultural area, food was consumed locally. Thus all organic waste from humans and animals were returned to land, completing the nutrient change cycle.

1.3 Effect of Chemical Fertilizer to Eco-System

High demand to the nutrient consumption for land or soil especially in the agricultural sector as well as to improve economic growth and alleviate food security issues, cause increasing demand of resources input such as Nitrogen, Phosphorus and Potassium usage over the years. Prolong usage of chemical supplementary nutrients to the land gives negative impacts to our environmental system such as deterioration of soil fertility, acidification and eutrophication [14]. Arable lands which are acidic could kill some beneficial microorganisms such as Azotobacter [15] that play an important role as a Nitrogen fixation agent for soil. The chemical fertilizer emission to pollute the ground and underground water resources. Water runoff that contains high concentrations of Nitrogen will enter lakes and rivers, thus causing the aquatic plant growth hence reducing dissolved oxygen concentration in water and as result reducing aquatic animals such as fish.

2.0 BIOFERTILIZER MARKET INVESTMENT

Instead of applying a smart plantation program to arable land, the organic fertilizer such as compost [16] and urea from animal manure, food or kitchen waste and agricultural waste can replace the basic function of chemical fertilizer to boost crops production. Unfortunately, microbes in the urea or compost need proper condition to react before feeding to the plant. Other than that, the quantity of microbes beyond organic fertilizer are unknown, so it is difficult to predict the efficiency of organic products. Dissatisfaction with the efficiency of organic fertilizer has contributed to innovation of biofertilizer in agriculture, which is generally safer, more eco-friendly and advantageous for plant health and also soil fertility especially in arable land.

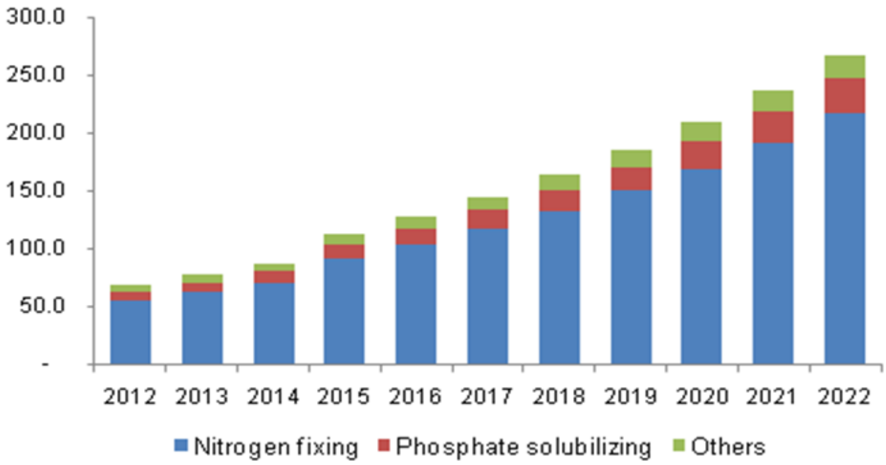

Figure 2 United State biofertilizer market revenue by product, 2012-2022.

Figure 2 illustrates the potential biofertilizer in the United States for 10 years from 2012 until 2022 for different products such as Nitrogen fixing and Phosphate solubilizing products. Global biofertilizers market size was estimated at USD 535.8 million in 2014 [17]. Excessive application of agrochemicals on crops leading to soil contamination and other environmental hazards is expected to be the key market driver over the forecast period. In addition to being an eco-friendly option, the product also helps to maintain soil and crop health. These are produced using organic wastes such as struvite and compost acting as substitutes for chemical-based fertilizers.

The EU "Common Agricultural Policy" promotes use of bio-based products along with organic farming and provides up to 30 percent of the budget as direct green payment to farmers complying to sustainable agricultural practices. Favourable regulatory scenario, especially in North America and Europe is expected to be a key driving factor for biofertilizer industry growth over the next seven years.

The government of India introduced a national initiative as part of its five-year plan which aims at increasing biofertilizer production, distribution and utilization thus favouring biofertilizers market growth. Low cost of these products as compared to their synthetic counterparts is expected to propel demand over the next seven years. However, lack of awareness among farmers particularly in emerging economies is expected to challenge industry growth over the forecast period [18-21].

Even though in Asia, many disadvantages of chemical fertilizer have been highlighted but their consumption is high compared with other regions. Malaysia as an example practicing biofertilizer in agriculture is not really accepted by plantations and smallholders because intensive labour is required [22]. The marketing strategy in biofertilizer products in Malaysia is through niche markets such as ornamentals, vegetables, forestry due to scope limitation belong to particular biofertilizer, for example rhizobial inoculum could only be applied to legumes, whether the grain legumes (such as groundnut, soybean, mung beans) or the leguminous cover crops (Centrosema, Pueraria, Mucuna, Calopogonium). The Effectiveness or successful symbiosis between the rhizobia and the legume roots will result in high efficiency at fixing atmospheric nitrogen, and subsequently less dependence on chemical nitrogen fertilizer [22].

3.0 BIOFERTILIZER PROMOTING HEALTHY PLANT GROWTH

Biofertilizer can be defined as preparation of live or lantern cells of efficient strains of Nitrogen fixation, phosphate solubilizing, or cellulolytic microorganisms used for seed, soil or composting agent [23]. The objective of preparation is to improve the number of microorganism in the soil as well as to accelerate certain processes of microorganism, thus increasing the nutrient availability of nutrients in a form which can be assimilated by plants [23]. Most resources or biofertilizers come from all organic sources including manure and functionally to promote plant growth.

The most commonly used organisms as biofertilizers are nitrogen fixers (N-fixer), potassium solubilizer (K-solubilizer) and phosphorus solubilizer (P-solubilizer), or combination with molds or fungi. Most of the bacteria involved in biofertilizer must have close relationship with plant roots such as, symbiotic interaction between Rhizobium and legume roots, Rhizobacteria inhabit on root surface or rhizosphere in soil. The functions of each microorganism are really specific; for example, only phospho-microorganisms mainly bacteria and fungi make insoluble phosphorus available to the plants [24]. Certain soil bacteria and species from fungi functionally convert insoluble phosphate into soluble form by secreting organic acid [24] which indirectly reduces the soil pH and brings about the dissolution of bound forms of phosphate.

The composition of nitrogen is abundant in air, about 80 percent is dominated by nitrogen and another 20 percent by other compositions such as water, hydrogen and other. Nitrogen in free state is unavailable for plants. A function of certain microorganisms such as azotobacter and Azospirillum that react as biological nitrogen fixing to converting the free state of elemental nitrogen into a form of nitrogen can be used by the plant through certain mechanisms and reactions. For example, Rhizobium inoculation is well known agronomic practice to ensure adequate nitrogen of legumes instead of using N-chemical fertilizer [24]. In root nodules the Oxygen level is regulated by special hemoglobin called leg-hemoglobin. This globin protein is encoded by plant genes but the heme cofactor is made by the symbiotic bacteria. This is only produced when the plant is infected with Rhizobium. The plant root cells convert sugar to organic acids which they supply to the bacteroids. In exchange, the plant will receive amino-acids rather than free ammonia. The symbiotic process can be simplified as Figure 3:

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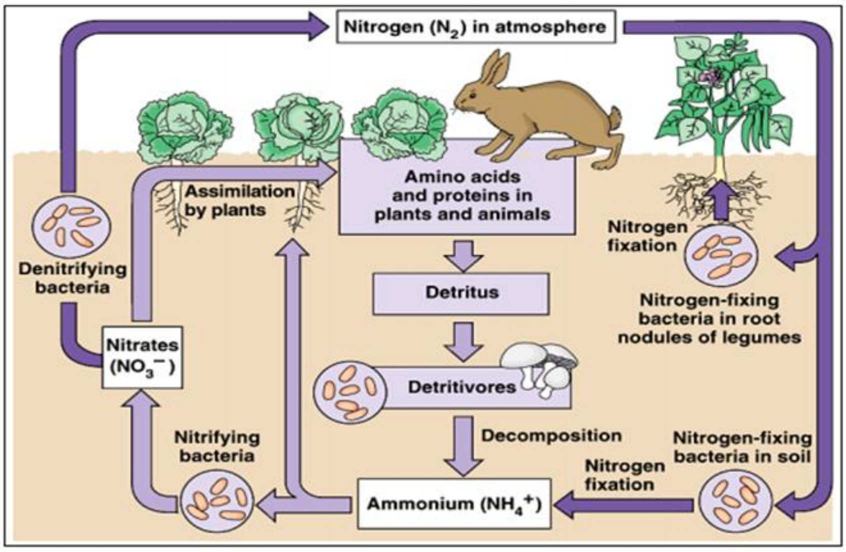

Figure 3 Nitrogen's Cycle [25].

The symbiotic interaction between plant and microorganism in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification. In nitrogen fixation process, nitrogen from atmosphere will be "captured" by nitrogen fixing bacteria in soil, the mutualistic relationship between microorganism and plant occur when infected nodule roots do metabolite reaction by converting sugar into organic acid for microorganism to survive and as return plant will received amino acid rather than free ammonia or elemental nitrogen.

The fixed phosphorus in the soil can be solubilized by phosphate solubilizing bacteria (PSB), which have the capacity to convert inorganic unavailable phosphorus form to soluble forms $(HPO_4)_2$– and (H_2PO_4)– through the process of organic acid production, chelation and ion exchange reactions and make them useful to plants. Therefore, the use of PSB in agricultural practice would not only reduce the high cost of manufacturing phosphate fertilizers but would also mobilize insoluble fertilizers and soils to which they are applied [26]. Evidence of naturally occurring rhizospheric phosphorus solubilizing microorganisms (PSM) and between 2 types of microorganism for PSM, bacteria-based are more effective in phosphorus solubilization than fungi [27].

Phosphorus solubilization is carried out by a large number of saprophytic bacteria and fungi acting cautiously to soluble soil phosphates, mainly by chelation-mediated mechanisms [28]. Phosphate solubilizes microorganism's secret organic acids and enzymes that act on insoluble phosphates and convert it into soluble form, thus, proving P to plants [29]. Inorganic P is solubilized by the action of organic and inorganic acids secreted by PSB in which hydroxyl and carboxyl groups of acids chelate cations (Al, Fe, Ca) and decrease the pH in basic soils [30].

The efficacy of Phosphorus solubilizing activity is determined by the ability of microbes to release metabolites such as organic acids, which through their hydroxyl and carboxyl groups chelate the cation bound to phosphate, the latter being converted to soluble forms. The PSB performance is varied and their population depends on different soil properties (physical and chemical properties, organic matter, and P content) and cultural activities. Each microorganism has a specific function and mechanism that can be utilized by the plant, for example Azetobacter, which is free living bacteria in the ecosystem that is usable as Nitrogen-fixing to supplied nitrogen in the form of plant can be used [24].

4.0 ADVANTAGES AND DISADVANTAGES OF BIOFERTILIZER

There are several things that need to be considered in biofertilizer making such as microbes' growth profile, types and optimum condition of organism, and formulation of inoculum. The formulation of inocula, method of application and storage of the product are all critical to the success of a biological product. In general, there are 6 major steps in making biofertilizer. These include choosing active organisms, isolation and selection of target microbes, selection of method and carrier material, selection of propagation method, prototype testing and large-scale testing [24]. The most common benefits offered by biofertilizers are in terms of environmentally friendly fertilizer, which does not give any harmful effect to the ecosystem. For example, the mutual interaction between plants and microorganisms is advantageous for both sides. The plant got better nitrogen assimilation, meanwhile microorganism got food from the plant via conversion of sugar to organic acid.

Practicing biofertilizer would improve soil fertility. Phosphorus solubilizes is carried out by a large number of saprophytic bacteria and fungi acting on cautiously to soluble soil phosphates, mainly by chelation-mediated mechanisms [28]. Phosphate solubilizers microorganism's secret organic acids and enzymes that act on insoluble phosphates and convert it into soluble form, thus, proving P to plants [29]. Inorganic P is solubilized by the action of organic and inorganic acids secreted by PSB in which hydroxyl and carboxyl groups of acids chelate cations (Al, Fe, Ca) and decrease the pH in basic soils [30]. The PSB dissolves the soil P through production of low molecular weight organic acids mainly gluconic and ketogluconic acids in addition to lowering the pH of the rhizosphere. The pH of the rhizosphere is lowered through biotical production of proton / bicarbonate release (anion / cation balance) and gaseous (O_2/CO_2) exchanges. Phosphorus solubilization ability of PSB has direct correlation with pH of the medium.

In terms of the environment and economy, the use of biofertilizers is thus desirable. However, chemical fertilizer is applicable to all crops, and not limited to a particular group of crops such as the legumes. Currently, grain legumes are no longer produced in large scale in Malaysia, and in rice producing areas of the country crop rotation of rice-legume-rice is not in practice, since double cropping per year (or sometimes 5 times in 2 years) is adopted. There is also no long fallow period between the rice planting seasons, thus rendering decomposing materials in the fields not readily available for the immediate planting season.

Biofertilizers are often perceived to be more expensive than the chemical fertilizers. This is more so, since the farmers and smallholders received fertilizers heavily subsidized by the government. Thus, only those nursery and farm operators who appreciate the benefits of certain biofertilizers will use them [22]. Another perception on biofertilizer is that its effect on the crops is slow, compared to chemical fertilizers. Special care such as storage, mixing with powders is also needed to handle microbial inocula so that they remain effective for extended use. These inoculants, too, favour certain environments. Concerning microbial inoculants, while some users realise their potential there is a difference of opinion on the effectiveness of microbial inoculants available in the market. Some felt that the performance of these products is often disappointing, unreliable, and not as claimed by the manufacturers [22]. The summary of advantages and disadvantages of biofertilizer is tabulated in Table 2.

Table 2 Summary of advantages and disadvantages of biofertilizer.

Advantages	Disadvantages
Environmental friendly	Applied for small group of crops only
Improve soil fertility	Not practical for season crops
Important for environment and economic	Expensive
	Slow effect to the crops
	Required stability of storage especially for longer shelf life
	Concerning the effectiveness of microbes for longer time utilizing

5.0 BIOFERTILIZER, FOOD SAFETY AND SECURITY

In the previous section (section 4.0), the advantages and disadvantages of biofertilizers to replace conventional chemical fertilizer have been discussed. Considering their versatile performances and their aim to help the farmer and community worldwide, there is a concern regarding food safety and security after application of biofertilizer. In particular, it is understandable to use microorganisms and the interaction between plants and soil surface. However, full risk of the main subject to respective crops is still scarce. Attempts have been made to fill the knowledge gap and the guideline for each inoculants utilization also discussed. Nevertheless, the risk associated with large scale agricultural or long term conditions for crops must be assessed properly. For example, certain microbes that applied to the crop may possibly switch its behavior to parasit even for the same crops. This phenomenon has been reported in 2006 by Kogel et al [31,32]. Keswani et al. highlighted the potential bacteria that might be harmful to humans [33]. This includes Burkholderia, Pseudomonas, Rhodococcus, Serratia, Acinetobacter, Stenotrophomonas, Enterobacter, Ochrobactrum, Klebsiella, Ralstonia and Bacillus, respectively. This statement is in agreement with study by Eberl and Vandamme, which stated that Burkholderia cepacia can work as PGP traits which include N_2-fixation however it may possibly be pathogens to humans [34]. Another study by Mendes et al., Pseudomonas (i.e *P. Fluorescens, P. Putida, P. Putrefaciencs, P. Stutzeri and P. Oseudoalcaligenes*) that has a great role as PGP potential is also known as possible pathogens which cause respiratory problems to human [35]. However, for current state, commercial biofertilizers is mostly formulated their products with organisms like *Actinorhizobium sp., Azospirillum sp., Azotobacter sp., and Rhizobium sp.*, which has lowest risk to human health and has been declared as safe for application [36]. Therefore, it is important to have proper biosafety screening tests especially in clinical and great tools to assess the whole genome sequencing, respectively.

Another possible risk to the environment eco-systems is that introducing the new microorganisms to the resident organism community may switch the resident microbial entirely. This indirect situation might also affect root architecture as well as plant diversity and composition. For example, A. Lipoferum isolated from maize has shifted the composition of the rhizosphere community at least within a month [37]. Trabelsi and Mhamdi reported that *Azospirillum sp.* can affect the rhizosphere community through N dynamic effects which suggested that many factors are involved especially in N_2-fixation [38]. The same trend also happened to commercial fungal biofertilizers. Applying foreign arbuscular mycorrhizal fungi (AMF) has significantly affected resident AMF communities [39]. From here, it shows that it is important to analyze the whole function of microorganisms at the same time reducing the gap between the impact on ecosystems as well as environmental health.

6.0 CONCLUSION

In conclusion, biofertilizer is a good practice for sustainable agriculture especially in plantations compared to chemical fertilizer application. Their advantages had been highlighted to sustain our environment and fix some eco-system issues such as deterioration of soil quality due to aggressive chemical fertilizing program, contamination at underground water resources and also pollution issues to the water surface such as at river, lake or ponds due to agriculture activity such as excessive nutrient contains to the river or pond. Indirectly unbalancing aquatic eco-system due to limited oxygen content in the water, thus leading to fatality to some aquatic animals such as fish.

Biofertilizers have a good market opportunity, even though in certain countries the market is not showing any positive response from farmers due to poor knowledge and skill in handling chemical fertilizer, thus contributing to high costing for fertilizing programs. Therefore approaches such as providing training centers are suitable to deliver knowledge and awareness among the farmer such as training programs for upgrading skill and knowledge to handling and storage biofertilizer. Training center also believed it was able to solve some agriculture issues, especially plantation through consultation from the expert. A closed relationship between farmers and research institutions and universities is able to promote better technologies and management systems to the plantation program so that the advantage of some microorganisms that are readily available can be utilized effectively.

In terms of the waste management system, proper facilities are needed for collecting agricultural waste such as manure and green waste, which is bio-degradable and easily decomposed with nature. Instead of having great potential for composting fertilizer, manure and green waste also can be processed to be carrier materials that are incorporated with microbial for producing biofertilizer. So, effective sterilizing technology and facilities are required to kill some pathogenic microorganisms that are harmful to desirable microorganisms for biofertilizers.

Other than varied harvesting quantity and qualities of product, over price fertilizing programs always become a nightmare to the farmer. Limited budget and funds provided by the local government can be seen as one of the influence factors for selection of fertilizing programs. A smallholder prefers to choose chemical fertilizer with the government budget due to fast and consistency of harvesting product. Meanwhile, applying biofertilizer needs extra hidden costing to mastering biofertilizer technologies, therefore adequate funds or incentive should be prepared to promote the biofertilizer program. Moreover, a campaign related to the environmental, plantation and input sources are important to create awareness among the community.

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