Bio-organo-chemical fertilizers: a new prospecting technology for improving fertilizer use efficiency (FUE)

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Abstract. Fertilizer use efficiency (FUE) has been the focus of agriculture cultivation practices to meet economic and environmental challenges. Unfortunately, available technology for improving FUE is somewhat impotent as no significant breakthrough in fertilizer technology during the last several decades. However, by harnessing the most active components of chemical, organic, and biological sources to produce a multigroup fertilizer so-called bio-organo-chemical fertilizer, it is possible to develop a new technology employing new paradigm in fertilization, i.e. improving soil capacity. Integration of microbes as consortium packages with the recent coating technology would be a promising approach to support sustainable agriculture. Intended targets are to reduce the volume of fertilizer application and consequently to lower cost and give more profits to the farmers. The microbial coating on chemical fertilizer technique has been invented by using epigenetic approach. If this technique can be employed in addition to currently available bio-encapsulation or carrier-based techniques, then the eminent consortium of microbes in chemical fertilizer formulation will become more efficient in the future. This paper reviews new technology development of a prospective bio-organo-chemical fertilizer to enhance FUE.

1. Introduction

Soil fertility is a manageable soil property and its management is of utmost importance for optimizing crop nutrition on both a short-term and a long-term basis to achieve sustainable crop production. Soil productivity is the ability of a soil to support crop production determined by the entire spectrum of its physical, chemical and biological attributes. Current management of soils focuses primarily on maximizing agricultural production. However, long-continued use of the major nutrients nitrogen, phosphorus and potassium can bring about nutrient imbalances in soil with effects, other than toxicity, that is deleterious to crop growth [1]. Fertilizer has a significant role in increasing agricultural production, productivity, farmer income, and national food security, the government highly concerns in managing the procurement and distribution of fertilizer to the farmers. To increase fertilizer use efficiency (FUE) and to minimize its negative impact on the environment have been the focal points in the world agriculture for a long time [2].

Soil productivity encompasses soil fertility plus all the other factors affecting plant growth, including soil management. Soil fertility connotes primarily the combined effect of chemical and biological properties and is probably the most important single soil factor affecting productivity. It is very important to increase FUE, since it affects farmer’s profit, especially in Indonesia whose
relatively low FUE and serious losses of nutrients. Fertilizers are considered as efficient when maximum yield is obtained with a minimum possible amount of fertilizer application. It is indeed difficult to quantify the efficiency of a particular fertilizer since it depends on (1) losses due to leaching, (2) losses in gaseous forms, (3) immobilization by chemical precipitation, adsorption on exchange complex and microbial cells, (4) chemical reactions between various components in fertilizers during mixing, before application to soil, (5) physical properties of soil, (6) chemical properties of soil and, (7) fertilizer characteristics. Completely, soil factors have a large influence on the transformation, fixation (adsorption) and leaching losses of N, P and K. Among the soil factors are its texture, proportion and amounts of clay (expanding, non-expanding and amorphous material), organic matter content, the cation exchange capacity, the concentration of ions on the exchange complex, the capacity of soil to release or renew the levels of exchangeable ion or to fix ions, soil pH, soil moisture, soil temperature, soil aeration and soil compaction. In selecting the fertilizer care should be taken to select such a type of fertilizer which will have minimum interaction with soil and the time and mode of application should be such as to ensure minimum immobilization of nutrients contained in the fertilizers [3].

According to Kassam and Friedrich [4], the utilization of external inputs of mineral nutrients and chemical pest control combined intensive tillage for crop production has been very successful in the sense that it has led to the intensification of agriculture to feed the world and avoid the Malthusian outcome. But this unprecedented success with intensive tillage-based production systems has come with a large environmental and human health costs and has not brought benefits to farm households around the world. As discussed by Anas [5] the significant impact of continues and irrational application of agrochemicals on agriculture and avoidance of using organic fertilizer since the years of the seventies have been noticed significantly in Indonesia. Soil degradation, environmental pollution, levelling-off and decrease in land productivity are among the negative impacts of long application of chemical fertilizers. In the last few years, the tremendous increase in the price of chemical fertilizer has stimulated scientists, governments and farmers to seek alternative fertilizers to chemical fertilizer. Taking the example of consumption of 21 million tons of nitrogen each year, and 45% of the amount is lost. The total loss of nitrogen can reach 9.45 million tons each year, which equals 20.5 million tons of urea [2].

The heavy loss of fertilizer has triggered a series of environmental problems. In some intensified agricultural areas in the north, the irrational application of nitrogen has led to the overrun of nitrates in the groundwater. Besides, there are other examples of environmental problems resulting from the irrational application of fertilizer, such as the accumulation of nitrates in vegetables, the increased emission of nitrous oxide in the air [31]. These problems lead to a decline in soil fertility. Soil fertility decline occurs when the quantities of nutrients removed from the soil in harvested products exceed the quantities of nutrients being applied. In this situation, the nutrient requirements of the crop are met from soil reserves until these reserves cannot meet crop demands. This results in a reduction of plant growth and yield. In improving fertility decline, the enhancing of soil organic matter and microbe is a necessity. The organic matter in soil not only supplies different nutrient elements but also improves physical conditions of soils, stimulates microbial activity, protects the soil from erosion, retards the fixation of nutrients, increases the buffering capacity, and helps in many other ways. In addition, as organic matter decomposes, it releases nutrients that are bound in the organic matter’s structure, essentially the ultimate slow release fertilizer. These benefits, in turn, increase the efficiency of applied fertilizers. Organic matter can also hold large amounts of water, which helps nutrients to move from soil to plant roots.

Less and less profits are enjoyed by farmers as the ever-increasing price and dosage of fertilizers, and a relatively stagnant commodity price continue. Those tremendous cases are now alarming in several parts of Indonesia or other developing countries. While farmers sell their product to the local market, the prevention or limitation mechanism of import product must be administered to help and accommodate local farmer. In the future, climate change issues could trigger the agricultural price significantly. In contrast, currently available technology for improving FUE is somewhat impotent as
no significant breakthrough in fertilizer technology during the last several decades. Therefore, to solving the FUE problem, the basic knowledge formulation both chemical and biology fertilizer are highly important. There is a tendency, however, to use one single product for all, which become more efficient in time and workforce. The urgency to formulate high efficient fertilizer with combine chemical, organic material, and microbe is considerably high. The current technology available is limited in a combination of chemical and organic fertilizer (organo-chemical fertilizer) and organic and microbes (bio-organo-fertilizer). In spite of this approach, the technology combining live microbe with chemical fertilizer is unavailable today. In the future, it is strongly expected to have a more simple, accurate, and end-user friendly products. Combination of the fertilizer design and microbial mechanism allow us to the possibility of creating bio-organo-chemical fertilizer. This paper aimed to reviews currently available technology and in relation to FUE and explore a new approach to fertilization by using a new paradigm, i.e. improving soil capacity to enhance FUE.

2. Challenges in Fertilization

In reality, it is extremely unlikely that the farmers from developing countries are making profit because most farmers face economic constraints that limit their effective demand for fertilizer, technical constraints that make it difficult to use fertilizer in combination with recommended crop management practices, and institutional constraints that limit the development of human capital and markets [6]. Public spending on fertilizer subsidies has increased far more than the production costs for the industry. In the manufacture of urea, natural gas is the main input and the increasing gas costs worldwide drove international urea prices upward by 50 percent between 2007 and 2008. However, the subsidy in Indonesia grew even faster, at 142 percent over the same period, suggesting that production costs are not the sole driver of increased spending [7]. FAO [8] reported that the world economy has broadly strengthened over the past three years and is expected to continue this strengthening during 2014-2015. World consumption of the three main fertilizer nutrients, nitrogen (N), phosphorus expressed as phosphate (P$_2$O$_5$), and potassium expressed as potash (K$_2$O), is estimated to reach 186.67 million ton (N, P$_2$O$_5$ and K$_2$O) in 2016, up by 1.4 percent over 2015 consumption levels. The demand for N, P$_2$O$_5$, and K$_2$O is forecasted to grow annually on average by 1.5, 2.2, and 2.4 percent respectively from 2015 to 2020. Over the next five years, the global capacity of the production of fertilizers, intermediates and raw materials is also expected to increase.

Judicious use of fertilizers and lime has a number of beneficial effects on soil properties and the surrounding environment beyond the obvious enhanced food and fibre production. According to Olson [1] although claims have been made that certain fertilizers are responsible for ‘hardening’ soils and making them less permeable to water, the effect, were measured, usually has been the consequence of poor management by the farmer, such as too much traffic over the soil surface or pulling anhydrous ammonia shanks through the soil when too wet. Extended use of nitrogen and phosphate fertilizers, especially the former, can, however, cause an acidification problem. As a general axiom, each kilogram of fertilizer nitrogen (other than sodium and potassium nitrates) requires about 1.8 kg of lime for its neutralization, while ammonium sulphate requires about 1.8 kg of lime for its neutralization, while ammonium sulphate requires three times more. Overloading the soil with phosphorus, especially in neutral to alkaline soils, can induce zinc deficiencies. When this problem is corrected by building up soil zinc levels with fertilization, an iron shortage may develop owing to the high phosphorus and zinc levels. A problem is thus created for which economic soil treatment measures do not presently exist. Similarly, loading soils excessively with potassium and nitrogen has been found to cause low magnesium levels in forages to the particular detriment of animals consuming forage [1]. The active ingredients in chemical fertilizers are highly concentrated and are provided to the plant too quickly, with the result that much of the fertilizer is not taken up and used efficiently; the excess is absorbed by the soil, often causing such common secondary effects as “nitrogen burn” due to dehydration, as well as contamination of groundwater.

Fertilizer’s agronomic potential is often unrealistic because of poor land and crop husbandry practices at the farm level. The failure to transmit research results about increasing fertilizer use efficiency (fertilizer/crop rotation interactions, use of micro-doses, soil type/fertilizer interactions) to
farmers is also a factor. Many “poor” management practices (late application or inadequate doses) often stem from farmers’ efforts to reduce risk. Response farming techniques and simulation models show promise for better risk management, but researchers need to transfer the lessons learned from these tools to many more farmers [6]. Rachman and Sudaryanto [9] added that national fertilizer production tends to be stagnant at an average of 75 percent utilization of the capacity. In growing markets today, some efforts to increase production capacity of fertilizer have been done through rehabilitation of urea factory in order to operate more efficiently. Up to now, the Ministry of Agriculture of Indonesia had listed 976 brands of fertilizer that consists of 296 brands of NPK Fertilizer and 407 brands of mix fertilizer. While organic fertilizer produced by the farmers reached 157000 tons. This diverse brands of fertilizer and wide product differentiation create a farmer’s unfavourable situation.

3. Current Status of Available Technology

3.1 Chemical compound fertilizer
There are many different analyses of compound fertilizers available throughout the world. These are traditionally supplied from one area/source, but increasingly are becoming available from other areas. Some products of this type are also manufactured by ‘blenders’ where the various components are simply mixed together in the appropriate proportions, as opposed to processes involving chemical reactions or wet granulation. Most ordinary compound grades can be supplied in bulk or bags. According to FAO [10] two grades, in particular, 15:15:15 and 20:20:0, are manufactured internationally in very large volume and the market for these behaves very much as a commodity market where supply and demand predominate as an influence. Reducing the volume and increasing the ability of fertilizer consequently to lower cost and give more profits to the farmers. Volume reduction could be achieved by using a controlled release fertilizer.

Liu et al. [11] reported that slow-release fertilizers generally have a slower release rate of the nutrient than conventional water-soluble fertilizers and controlled-release fertilizers. Slow-release fertilizers can occasionally be released very quickly when excessive moisture and high temperatures occur in the same period of time. Controlled-release fertilizers contain a plant nutrient in a form that delays its availability for plant uptake and use after application, or that extends its availability to the plant significantly longer than “rapidly available fertilizers” such as ammonium nitrate or urea, ammonium phosphate, and potassium chloride. To match crop nutrient requirements, the ideal fertilizer should have this characteristic: the nutrient release matches the nutrient requirements of the crop throughout all of the plant growth stages. Fortunately, using deliberate applications of controlled-release fertilizers and slow-release fertilizers in specific circumstances where they are appropriate can accommodate timely plant nutrient demand requirements, maximize nutrient use efficiency, and minimize environmental concerns. In 1992, Goenadi [12,13,14,15] reported that slow release fertilizer is beneficial for estate crop seedlings (cocoa seedlings, oil palm seedlings, rubber seedlings) and showed the potential release period of the fertilizer is approximately 32 months. The newest technology in 2016 of an environment-friendly slow release fertilizer of zeolite-based nano-composite has been studied by Lateef et al. [16]. The zeolite-based nano-composite (ZNC) was synthesized by simple impregnation of nutrient. While Zhou et al. [17] developed a research of controlled-release urea fertilizers with synthesis composite hydrogels from inorganic-organic hybrids technique. Coating large urea particles with polyethylene (PE) membranes for controlled-release fertilizers also has been conducted by Yang et al. [18]. This type of fertilizer offers significant reductions both in volume and cost as its consequence.

3.2 Organochemical fertilizer
Organic products are eco-friendly natural sources, which can be considered as an alternative to sustainable agriculture development. Chen [19] reported that the effects of organic fertilization and the combined use of chemical and organic fertilizer on crop growth and soil fertility depend on the application rates and the nature of fertilizers used. In general, the application rates of organic fertilizer
mostly are based on crop N need and estimated rates of organic fertilizer N supply but do not consider the amount of P and K provided with organic fertilizer. However, the N/P ratio of organic fertilizer usually is significantly lower than the N/P uptake ratio of the crop. Therefore, basic organic fertilizer on N supply typically results in P addition in excess of the crop’s need. Nutrients, salt or heavy metal accumulation has also been reported in many papers, especially for the long-term or heavy use of organic fertilizers with higher contents of P, K, salt, or heavy metals. However, while the use of chemical fertilizers is defective in the areas of cost, scarcity and toxic residual effects, the use of organic manure becomes imperfect in terms of time and labour required for preparation, as well as the huge quantities needed to meet crop nutritional needs.

Organic fertilizers are still used in a bulky volume. Taking the most active component of organic materials called humic substance is very important. When humic substance extraction is available, the disadvantages bulky characteristic of organic fertilizer will be reduced. Positive correlations between the humus content of the soil, plant yields and product quality have been published in many different scientific journals. Quality of humic substances extracted from composts is influenced by the composting ingredients and techniques.

Several approaches that have been reported by Santi and Goenadi [20] such as organo-chemical fertilizer with humic substances utilization. Fertilizers with humic substances can be used on different types of soil, as well as in technologies for improving degraded or contaminated soils and they proved effective on a wide range of cultures. Pettit [21] explained that humic substances are the components of humus and as such are high molecular weight compounds that together form the brown to black hydrophilic, molecularly flexible, polyelectrolytes called humus. The research of [20] was to developed organo-chemical fertilizer with rock phosphate and urea. The organic materials which obtained from oil palm plantations then processing by compost methods. Afterwards, composts, rock phosphate and urea are combined through granulation process resulting of 10% C-organic, 11% N, 8% P, 1% K and 4% humic acid. While N and P are originally from rock phosphate and urea. The reaction of an organic acid from compost with rock phosphate reported increasing P content. Moreover, biomass dry weights of the seedlings applied with 100 g organo-chemical fertilizer plus 10 g KCl to each seedling were significantly different compared to the standard dosage of chemical fertilizer. Another key mechanism, which maximizes fertilizer efficiency and relates to a function of humic substances, is a reduction in the toxicity and leaching of nitrogen compounds into subsoil water. Humic substances hold these major plant nutrients in a molecular form which reduces their solubility in water. These binding processes reduce leaching nitrogen into the subsoil and help prevent volatilization into the atmosphere. This organo-chemical fertilizer could be applied as a conventional fertilizer substitute.

3.3 Bio-based fertilizer
Biofertilizers are microbial inoculants consisting of living cells of micro-organism like bacteria, algae and fungi alone or combination which may help in increasing crop productivity. Biological activities are markedly enhanced by microbial interactions in the plant rhizosphere. In contrast, organic fertilizers are obtained from animal sources such as animal manure or plant sources like green manure. For example, vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product. Judy [22] added that biofertilizer contains a variety of beneficial microorganisms inside, but all microorganisms in organic fertilizer after high-temperature treatment substantially are failed to survive, which is difficult to provide beneficial soil microbes.

A number of approaches have been investigated for incorporating microbes, or microbial compositions into fertilizer compositions. The decontaminated manure and humic acid are mixed as dry ingredients with Ca(H₂PO₄)₂, KCl, and Urea then fed into an agglomerator. A 50% aqueous suspension of the Bacillus spores is sprayed-on in the agglomerator and the resulting moistened ingredients formed into prills in a revolving drying tunnel. Other approaches are coating fertilizer particle with 5-35 dry weight % biomass solid particles with a particle size below 400 microns and an
oil or wax based dispersant. There are also approaches which disclose fertilizer compositions comprising decontaminated manure and Bacillus spores in combination with a humic acid derivative and, optionally, one or more of N, P, K compounds. The dry ingredients are first mixed then ground to 100-150 mesh. The Bacillus spores are sprayed-on and the resulting product prilled via a rotating drier.

Currently, the use of organic fertilizer by farmers is still low at about 21 percent. This is due to the highest retail price of organic fertilizer which is almost equal to the highest retail price of Urea fertilizer [8]. Biological fertilizer is used in very limited volume and still in separate formulation. One product may cover mineral solubilizing microbe, and the other one provides root inoculums microbe. Biofertilizers are generally applied to soil, seeds or seedlings, with or without some carriers for the microorganisms. Regardless of methods, the number of cells reaching the soil from commercial products is smaller than the existing numbers of soil or rhizosphere microorganisms; these added cells are unlikely to have a beneficial impact on the plant unless multiplication occurs. In addition, the population of introduced microorganisms will decline and be eliminated in a very short time, often days or weeks. The formulation of inocula, method of application and storage of the product are all critical to the success of a biological product. Short shelf life, lack of suitable carrier materials, susceptibility to high temperature, problems in transportation and storage are biofertilizer bottlenecks that still need to be solved in order to obtain effective inoculation [30].

More organic matter fertilizer means also more nourishment for bacteria, fungi and other organisms in the soil. More active soil microorganisms also reduce pest populations in the soil. Some mechanistic evidence now proving that microbial consortium is key to reveal and solve not only nutrient deficiency but also protection from pest and disease. The idea to compile many broad spectra of microbial consortium package in one product now is undeniable. Even improving the chemical aspect is also possible to tackle. In the near future, one-stop fertilizer product can be distributed to the user, especially to the farmers. The benefit is also to enhance FUE by reducing chemical fertilizer dosage.

4. New Approach

4.1 Liquid vs carrier-based biofertilizer
If a scientist can integrate microbes as consortium packages with the recent coating technology, it would be a promising technology for sustainable agriculture. A preparation to preserve organisms, to deliver them to the target regions, to improve their biological activity of a consortium of microorganisms provided with a suitable medium, to keep up their viability for certain period will help in enhancing the biological activity on the target site. Pindi and Satyanarayana [23] analysed formulations comprise inoculums in semi-dry condition, includes dust, granules and briquettes, based on the particle or aggregate size. This group also comprises wettable powders formulated in dry powder. These powders require liquid or water as carrier just before the application to activate the inoculum. Dust usually range from 5-20 mm in size and require low absorbance inert diluents as carriers. Low dust particles, i.e. less than 10 mm size adhere best on the target site but are hazardous when inhaled. About 30% of the dry weight of dust contains organisms as suspension. They are normally prepared by feeding the organism into an air stream for mixing with a blender. Particle size, bulk density and flowability are extremely important.

Pindi and Satyanarayana [23] also reported the pros and cons of liquid biofertilizer (LBF) and carrier-based biofertilizers (CBBF). Liquid biofertilizer formulation is the promising and updated technology of the conventional carrier-based production technology which in spite of many advantages over the agrochemicals, left a considerable dispute among the farmer community in terms of several reasons major being the viability of the organism. Shelf life is the first and foremost problem of the CBBF which is up to 3 months and it does not retain throughout the crop cycle, LBF, on the other hand, facilitates the long survival of the organism by providing the suitable medium which is sufficient for the entire crop cycle. CBBF are not so tolerant to the temperature which is mostly unpredictable and uncertain in the crop fields while temperature tolerance is the other advantage of the liquid biofertilizers. LBF may have a better effectiveness than the solid one. The
range of possible contamination is very high as bulk sterilization does not provide the desired results in the case of CBBF, whereas the contamination can be controlled constructively by means of proper sterilization techniques and maintenance of intensive hygiene conditions by appropriate quality control measures in the case of LBF. Moisture retaining capacity of the CBBF is very low which does not allow the organism viable for a longer period and the LBF facilitates the enhanced viability of the organism.

Goenadi [24] with Saraswati invented a product namely *EMAS* (Enhancing Microbial Activities in the Soils) fertilizer and conducted a research from 1992 to 1999. *EMAS* fertilizer is granular-shape biofertilizer first in the world (Patent No ID 0000294S in 1998) and significantly proved to enhance FUE up to 25% by saving chemical fertilizer dosage and increasing 10% to 30% crops yield depend on crops variety. Granulation is made by coating the granular core used a rotary-spraying drum mixer. *EMAS* fertilizer has several multiplier effect benefits such as reducing handling and transport cost, reducing environmental pollution, and increasing farmer income. Goenadi [24] stated that *EMAS* could save up to 50% conventional NPK fertilizer for soybean, chilli, and sugarcane. This wide-spectrum effect is caused by high quality and a pure isolate of microbes. Goenadi *et al.* [25] reported that an efficient bio-fertilizer product i.e. *EMAS* has been successful developed by using active ingredients consisting of *Azospirillum lipoferum*, *Azotobacter beijerinckii*, *Aeromonas punctata*, and *Aspergillus niger* native of tropical soils. The application of 6.25 g *EMAS* per plant (equivalent with 83.125 kg/ha) + 50% inorganic fertilizer recommended dosage for tea, could reduce the application of inorganic fertilizer dosage by 50% and resulted in the growth of the plant which was better than that of inorganic fertilizer. In addition, evaluation of the effectiveness of *EMAS* biofertilizer in corn at Pelaihari, South Kalimantan indicated that based on the current production value and a total of cost production, reducing 25, 50 and 75% conventional fertilizer provides the planters with 1.44, 1.13, and 1.12 revenue-cost ratio. The yield of a dry grain of corn was higher (+41.8%) by application of 75% standard dosage and 1 g *EMAS* biofertilizer/tree (53.3 kg/ha) than by standard dosage of conventional fertilizer. *EMAS* biofertilizer’s field experiments also were conducted in plantation crops (tea, rubber, cocoa, oil palm, and sugarcane), food crops (paddy and corn), horticulture (potatoes), and spice. In addition, introducing the biofertilizer in soil provides a more stable soil aggregate and improves its fertility status.

Carrier-based biofertilizers have already proven to be the best over the agrochemicals and have been showing the tremendous effect on the global agricultural productivity for the past two decades. Rectifying the disadvantages of the carrier based biofertilizers, liquid biofertilizers have been developed which would be the only alternative for the cost-effective sustainable agriculture. Carrier and coating material are inseparable matters on the next research of bio-organic chemical fertilizer. Schoebits *et al.* [26] reported that the promising research should be based on what the carrier and how to coat it. The carrier is usually a convenient and economical material, which is able to release slowly viable cells in high-quality physiological condition, containing one or more beneficial bacteria. There are a number of alternative carriers and formulations for delivery of bacteria: talc, vermiculite, perlite, polyacrylamide, carrageenan, alginate, alginate–starch, alginate–humic acid, and powder formulations, although the most practical carriers used worldwide on commercial crops are peats, liquids, and clays.

### 4.2 Encapsulation technique

The state-of-the-art knowledge on bioencapsulation seems as a protective coating layer for microbes even with the mixture of chemical fertilizer one. According to Schoebits *et al.* [23], the principle of rhizobacteria bioencapsulation is to protect the microorganisms introduced into the soil and to ensure a gradual and prolonged release. The degradation rate of the encapsulation matrix will have a direct relationship with the biological activity of the soil microorganisms. The dried capsules can be stored at room temperature for a long period presenting a favourable environment for bacteria and reducing the risk of decreased survival. These inoculants can be improved by incorporating essential nutrients for bacterial growth, transforming the capsules in bioreactors, which are capable of increasing the number of encapsulated bacteria inoculated into the soil.
Schoebitz et al. [26] reported that bacterial inoculants have solved many problems associated with traditional peat inoculants, which originate great variability in peat quality. Numerous advantages related to the bioencapsulation of rhizobacteria are found, for instance, controlled release of bacteria into the soil, protection of microorganisms in the soil against biotic and abiotic stresses, and contamination reduction during storage and transport. Instead, bioencapsulation provides a niche where rhizobacteria are protected from the soil stress. Furthermore, the liquid inoculum, after being introduced into the soil has an instantaneous and very fast release and the rhizobacteria are delivered only in the initial moment of the plant growth. Alternatively, the encapsulated inoculants confer a gradual cell release that achieves long-term fertilizing effects. Agronomically this approach is very economical and has the lower cost compared with conventional fertilizer. Intended targets are to reduce the volume of application and consequently to lower cost and give more profits to the farmers.

The inconvenience of bioencapsulation technology must not be ignored. Many of the bioencapsulation devices are confectioned to produce beads in laboratory conditions and very small scale. This allows testing encapsulated formulations only in growth chambers and greenhouses conditions. To produce a large amount of inoculant, trials on large fields are required to use innovative bioencapsulation devices [26].

4.3 Bio-enrichment of chemical fertilizer
The urgency to enriched chemical fertilizer with the organic and biological material is an unavoidable matter. An economically feasible and environmentally product of fertilizer is desirable. Reveal the pathways of microbial life and adaptation mechanism to extreme conditions is the solution. The epigenetic approach provides an imminent path of fertilizer development. Especially in integrating microbes onto chemical and/or organic fertilizer. Epigenetic processes control central genomic functions such as the utilization of genetic information over the course of life. Epigenetic processes are controlled by adding and removing epigenetic modifications on the genes. Epigenetic is different with transgenic. Epigenetic modifications are added at different molecular levels and form a complex combination of positively and negatively regulating molecular signals. Epigenetics describes mechanisms that lead to change, heritable structural and activation states of the chromatin without changes to the primary nucleotide sequence. This molecular genetic definition describes some characteristics but leaves out some aspects of the functional consequences and other possible levels of epigenetic control. Epigenetic mechanisms are located at several levels. On the genome, the levels are those of DNA modifications and chromatin. Partly decoupled from the genome there are modifying proteins and non-coding RNA, whose site of action is in the nucleus or the cytoplasm. The common property of all three of these levels of the epigenetic mechanism is that they influence the function and regulation of genes in a long-lasting but at the same time reversible manner [27]. By understanding the potential strain of microorganisms, the more effective results can be obtained through the interaction with another active component. Soil microbiology no doubt holds the keys to unlocking some of the important new opportunities for enhancing nutrient management and crop production.

Harnessing the most active components of chemical, organic, and biological sources to produce a multigroup fertilizer is the most promising solution nowadays. One formulation called bio-organo-chemical fertilizer can be developed by understanding the characteristics of each fertilizer above and the approach is to combine them without reducing its advantageous. The combination of microbial as coating agent of granular chemical fertilizer and its effects towards plant and soil ecosystem should be explored and researched more. Schoebitz et al. [26] reported that the success of using microbial inoculants introduced into soil requires the survival of adequate numbers of bacteria reaching suitable habitats where they can thrive. For these reasons, the formulation is a key factor in the success of microbial inoculants. Chen [19] also reported that P-based compost application with the urea supplement was the best fertilizer management strategy for the soil and would avoid the accumulation of nutrients, salt and heavy metals. Organo-zeolitic bio-fertilizer is also developed by [31] composed of organic waste and crushed zeolitic rock, containing Clinoptilolite and commonly Mordenite zeolite, functions biologically in sponsoring nitrification. Ammonium ions, provided from the degradation of
the organic waste, are adsorbed to the zeolite mineral surface thus avoiding a loss to the atmosphere by volatilization. Oxidation of the ammonium ions, by soil nitrifying micro-organisms, provides major and trace element nutrients. Analysis of pore water, from substrates amended with the bio-fertilizer, has shown that its electrical conductivity is orders of magnitude higher than that of pore water from untreated substrates. This is reflected in the high ionic concentration of cations present, which covers a wide range of elements, providing essential major and beneficial trace-elements in the ionic state that are directly available for plant uptake.

New technology that has been used is the application of spores or live cells of *Bacillus laterosorus* strain CM-3 for increasing the yields of grain crops. Using its adaptability, the spores are applied to crops as an aqueous suspension obtained directly from the fermentation of the CM-3 microorganism or via re-suspension of a spray-or freeze-dried version. The use of microbial supplements added to separate products from traditional fertilizers, introduces complexity in the target applications of agronomy, reducing their attractiveness and compromising customer adaptation and dosage compliance. Additionally, the compositions of the present invention also provide plants with higher Brix index, antioxidant levels, and chlorophyll content. The invention further provides a method of producing the fertilizer product in a solid form. The composition and methods are applicable to any microbial-based treatment designed for agronomy or agricultural applications [29].

Combination technology of microbial carrier system and chemical fertilizer such as existing particle already present in the fertilizer, e.g. Urea, Diammonium Phosphate (DAP), Potassium Chloride, or a filler particle or NPK might trigger FUE more and more. Carpenter [29] reported that the ability of *Bacillus, Pseudomonas*, and *Streptomyces* as a coating for granular NPK. Binding or coating agent is required to attach the dried microorganisms to the solid particles. Another approach is by spraying the microorganism in the liquid phase while chemical fertilizer is mixing. The adaptability of this bacteria mixture coated on the carrier system in an amount from 10^6 to 10^11 colony forming units (CFU) per gram of carrier. Carpenter [29] also developed bacteria coated carrier and drying the coated carrier which the carrier is inert solid materials. The results showed that the activity of microbes on coated urea particles with this approach show significant nitrification from the coated urea sample indicating activity of the mixed microbial system under realistic use conditions. Parallel respirometer studies confirmed significantly higher evolution of CO₂ and consumption of O₂ on the coated urea sample than on the non-microbial control consistent with microbial growth. Agronomically, this approach can improve plant productivity and keep the health of the soil.

### 4.4 Prospect of bio-organo-chemical fertilizer

Improvements in management and nutrient use efficiency allow productivity to grow relatively faster than the growth rate of inputs, except in regions where fertilizer is underused. The soil and plant system is very dynamic. In addition to the chemical aspects, there is a complex biological system associated with nutrients that are normally overlooked in most nutrient management planning. The interactions of the plant root, soil mineral and organic particles, and the various kinds of micro-organisms (bacteria, fungi, protozoa, etc.) all play a role in determining the availability of nutrients from the soil to the plant. As fine-tuning of the dynamic soil-plant nutrition system continues, more economic benefits of some microbial interactions may be identified, and potential for managing some of these may be developed. This could open new aspects of plant nutrition in coming years.

The prospect of bio-organo-chemical fertilizer products is considerably high in the future. Three important sources: chemicals, organics, and microbes, can be incorporated in one formula. Bio-organo-chemical fertilizer can be realized by the new approach of chemical fertilizer enriched with organic and biological agents. These processes induce an epigenetic shift in the organisms resulting in the expression of specific attributes and generating significant performance across a broad range of application conditions. This is very important in improving soil capacity and increasing FUE. Inorganic fertilizer plays a critical role in the world’s food security, but the highest yields are often the result of using organic including microbial and inorganic sources together. Integrated soil fertility management (i.e. optimizing fertilizer and organic resources, along with improved genetics, and using...
modern technology) through bio-organo-fertilizer is critical to optimizing food production and efficient use of plant nutrients. Using the right source, at the right rate, at the right time, and in the right place, is a basic principle of nutrient management and can be adapted to all cropping systems throughout the world to ensure productivity, profitability and environmental stewardship are optimized. Putting the right information in the hands of the right people ensures achieving efficient use of plant nutrients [30].

5. Conclusions

Growing global population demands the safe and sufficient food for the survival of humankind. Soil health has become the greatest assertion for the scientific community in this ever-growing polluted globe. Crises of agricultural land day by day, vertical increase in the cost of agriculture input technologies are leading to transitions in the farming community. In such an agro-critical scenario, a multifaced solution for different constraints in agro-industry is necessary. A new paradigm in fertilization is not just to develop new fertilizer product and improve application technique, but more importantly is to improve soil capacity in cycling the nutrients effectively as well. Efficient plant nutrition management should ensure both enhanced and sustainable agricultural production and safeguard the environment. Chemical, organic or microbial fertilizer has its advantages and disadvantages in terms of nutrient supply, soil quality and crop growth. Developing a suitable nutrient management system that integrates the use of these three kinds of fertilizers may be a challenge to reach the goal of sustainable agriculture; however, much research is still needed. Research on microbial adaptability on chemical fertilizer are strongly needed for more economic and environmentally friendly agriculture in the future.

6. References

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