ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2710-6012 (Online)
CODEN: JWBMAO

Journal of Wastes and Biomass Management (JWBM)

DOI: http://doi.org/10.26480/jwbm.01.2021.01.08

REVIEW ARTICLE

PROMOTION OF ORGANIC AND SUSTAINABLE AGRICULTURE THROUGH THE USE OF BIO-FERTILIZERS

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ARTICLE DETAILS

Article History:

Received 29 September 2020
Accepted 30 October 2020
Available online 17 November 2020

ABSTRACT

Researchers have encouraged the methods of organic farming by the usage of "Bio-fertilizers" to stop chemical pollution in farmlands. Bio-fertilizer encompasses microorganisms that promote the sufficient supply of nutrients to the host plants and assure their appropriate development of growth and regulation in their physiology. Literally, with the target to feed people and support sustenance of life, agriculture was developed a long time ago. Nevertheless, the burgeoned population over the years resulted in depletion of scarce resources at such a high rate. The impacts of such detrimental enactment started to cause many unprecedented events in the nature, where agriculture was also no more an exception. In order to, revive the productive capacity of the soil, to feed increasing population; unsustainable practices like the use of chemical fertilizers came into existence. It might have acted as a boon during its initiating days, but after long usage of it for decades it pushed the agricultural sector even to the brink of deterioration by over-exploiting many of its' natural states. So, green agriculture, where bio-fertilizers are also observed as biotic components that intensify natural conditions of soil, began to re-surface as a solution for implausible actions taking place in agriculture. Organic farming and sustainable agriculture are gaining popular worldwide. And one of the best options to achieve that goal is by using bio-fertilizers. There are different types of microbes that act as bio-fertilizers, where Mycorrhiza, PGPRs, PGPMs are also included, which seems to be effective for plants, soil health, environment in different ways that the biotechnological researches and experiments are also taking place in the world to supplement bio-fertilizers capacities ensuring sustainability in Agri-food system and the environment.

KEYWORDS

Bio-fertilizers, Green Agriculture, Induced Systemic Resistance, Organic farming.

1. Introduction

As the civilization of human passes by, numerous modern developmental survival instincts and knowledge gets developed, it gets past down in history from generation to generation in more refined and evolved form for longevity race, giving initiation to different eras. Agriculture got introduced as basic innovation during past days as subsistence farming. However, a sudden rise in the population of the world increased more demands on the food supply that arouse a situation of pressure on agriculture to increase the food production to fill many hungry stomachs. To meet the food demand of an overwhelming population, agriculture is being more scientific which is followed by the green revolution.

At the beginning of the "Green Revolution", chemical fertilizers definitely became blessings for intervening the potentiality of soil to enhance production. But, as the over-exploitation of scarce resources along with the injudicious use of chemical fertilizers increased, negative impacts in our ecosystem became more vivid, globally. Although the use of chemical fertilizer has aided in yield per unit area to some extent, but has also affected by increasing the inappropriate use of synthetic fertilizers too (Chandini et al., 2019). Imprudent use of chemical fertilizer has hardened the soil, declined fertility status, strengthened pesticides and release greenhouse gases, thereby bringing hazards to human health and crop environment. Also, use of chemical fertilizers causes water pollution, chemical burn to crops, increased air pollution, acidification of the soil and mineral depletion. Different researches has already proved how chemical fertilizers invites serious challenges to balanced organic farming and sustainable agriculture (Stamenković et al., 2018).

2. Idea on Green Agriculture

The idea on Green agriculture has become popular among environmentalists as a potential solution to problems regarding unsustainable agriculture nowadays. According to the United Nations, Green agriculture incorporates ideas and guidelines from different conceptual areas.

These are fair trade, ecological agriculture, *organic* or biodynamic agriculture, as well as conservation agriculture. Mainly, it integrates the concept of local farming techniques and practices to modern farming with the sustainability concepts to improve natural agricultural techniques. With prior to grasp of such wide-ranged and complex topic, realization on bio-fertilizers for agriculture came as a significant boon, and its adoption resulted in significant positive outcomes too.

Quick Response Code	Access this article online	
	Website: www.jwbm.com.my	**DOI:** 10.26480/jwbm.01.2021.01.08

Cite The Article:Barsha Kc, Bidhya Pandey, Himani Chand, Prashamsa Bhusal, Sukriti Pandit, Saugat Khanal(2021).Promotion Of Organic And Sustainable Agriculture Through The Use Of Bio-Fertilizers.*Journal Of Wastes And Biomass Management, 3(1): 01-08.*

3. Organic Farming and Sustainability Concept

Organic farming is an approach of sustainable agriculture that provides a natural way of crop management by using animal and plant-based local organic resources that are highly enriched in nutrients. It enhances microbial activities and improves soil health. Organic farming is an efficient and promising agricultural practice for environmental sustainability because it supports yield stability, improved soil health, no environmental concerns, organic food and reduction in the use of synthesized fertilizers (Dhiman, 2020). The goal of sustainable agriculture is to meet society's food needs in the present without compromising the ability of future generations to meet their own needs. Practitioners of sustainable agriculture seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Sustainable agriculture produces its own inputs (fertilizer from animals, feed grown on the land) and manages its outputs (crop waste, manure) in a closed-loop cycle. It contributes to soil fertility, clean water systems, biodiversity, and other ecosystem services, instead of than depleting.

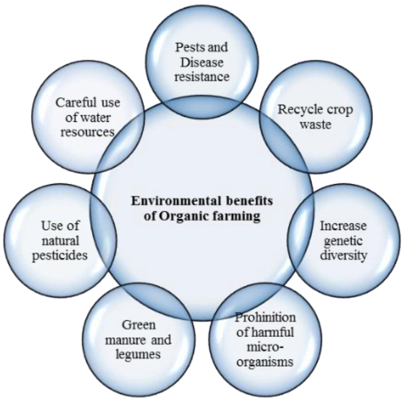

Figure 1: Environmental benefits of Organic farming (Source: Medium, 2018)

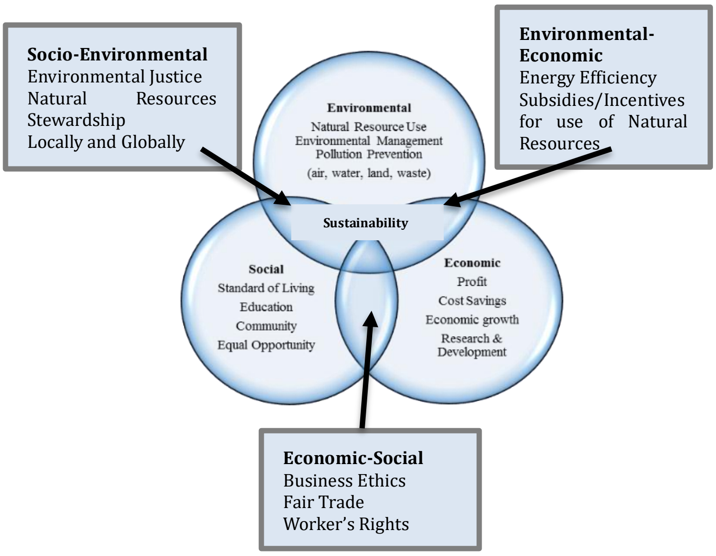

Figure 2: Three spheres of sustainability (Adli Aminuddin et al., ,2015)

4. Biofertilizers

Biofertilizers play a critical role in maintaining long-term soil fertility and sustainability (Mishra et al., 2013). Bio-fertilizers, which enhance the microbial activity in the soil, can act as the effective solution to make agriculture sustainable. These are the microbial inoculants containing the living or latent cells of efficient strains used for application to seeds, soil or composting areas with the purpose to accelerate the microbial process to augment the availability of nutrients that can easily be assimilated by plants, colonize the rhizosphere or the interior of the plant and promotes growth by converting nutritionally important elements to available form through the biological processes such as nitrogen fixation and solubilization of rock phosphate (Yadav and Sarkar et al., 2019).

4.1 Different types of bio-fertilizers

Bio-fertilizers enriched plants with nutrients through the natural processes of nitrogen fixation, solubilizing phosphorus, and stimulating plant growth by the synthesis of growth-promoting substances. The microorganisms in bio-fertilizers restore the soil's natural nutrient cycle and build soil organic matter.

Bio-fertilizers are divided into different groups depending upon the micro-organisms they contain. They are:

Nitrogen-fixing bacteria: Nitrogen fixation is the second most important process in crop production, after Photosynthesis process. Photosynthesis captures sunlight and produces energy, and nitrogen fixation uses nitrogen gas to form ammonium. 300-400 kg N/ha/year can be produced for free by Nitrogen fixation and it can also add 20-200 kg of N per ha (by fixation), liberate growth-promoting substances and increase crop yield by 10-50% (Ghany et al., 2014). Some common Nitrogen fixers:

Rhizobium: It belongs to the family Rhizobiaceae and is symbiotic in nature which can fix nitrogen amount to 50-100 kg/ ha with legumes only. *Rhizobium* can fix atmospheric nitrogen in symbiotic association with legumes and also with certain non-legumes like Parasponia (Mahdi et al., 2010). The rhizobia consist of approximately 50 species in about 12 genera.

Azotobacter: *Azotobacter* are gram-negative free-living bacterium in the rhizosphere soil of many plant species, discovered by Beijernick. Under in-vitro conditions, the isolated culture of *Azotobacter* has ability to fix about 10 mg nitrogen g^{-1} of carbon source. Due to a lack of organic matter and the presence of antagonistic microorganisms in the soil, the number of *Azotobacter* rarely exceeds 104 to 105 g^{-1} of soil (Mahdi et al., 2010). Alginic acid, a compound used in medical industry and in food industry as an additive in ice creams and cakes, is produced by some species of *Azotobacter* (Ramasamy et al., 2020).

Azospirillum: *Azospirillum* belongs to the family Spirilaceae, heterotrophic, and associative in nature. They also produce growth-regulating substances along with the nitrogen-fixing ability of about 20-40 kg/ha, (Mahdi et al., 2010). The organisms suit well in rice field conditions as they are micro-aerophilic, some are aerobic motile and gram-negative in nature (Ramasamy et al., 2020).

Blue-green algae *(Cyanobacteria)* and *Azolla:* These organisms are also known as "paddy organisms" as they fix 20-30kg N/ha in submerged rice fields, they produce Auxin, Indole acetic acid and Gibberellic acid and are phototrophic in nature that belongs to eight different families (Mahdi et al., 2010).

Phosphate solubilizing bio-fertilizer: Phosphorous is the key element for plant growth after Nitrogen. Phosphate solubilizing bacteria (PSB) which have the capacity to convert inorganic unavailable phosphorus form to soluble forms HPO_4^{2-} and $H_2PO_4^-$ fixes phosphorus in the soil through the process of organic acid production, chelation and ion exchange reactions and make them available to plants (Itelima et al., 2018). The bacterial genera with the capacity to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate are *Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Micrococcus, Aereobacter, Flavobacterium and Erwinia* which are both aerobic and anaerobic strains, with a prevalence of aerobic strains in submerged soils (Mahdi et al., 2010).

Phosphate mobilizing bio-fertilizers: The organic form of Phosphorous present in soil are mineralized for plant utilization by Phosphate mobilizing bio-fertilizers. They work by scavenging phosphates from soil layers and mobilizing the insoluble phosphorus in the soil to which they are applied (Itelima et al., 2018). Mycorrhiza is prominent P mobilizers in a symbiotic association with plant roots in which the fungal partner is benefited by obtaining its carbon requirements from the host's photosynthates and the plant, in turn, gains the much-needed nutrients which would otherwise be inaccessible to the host (Sharma et al., 2012).

Zinc Solubilizing bio-fertilizers: The above-mentioned bio-fertilizers only provide major nutrients. And plants need to be supplied with the micronutrients. Zinc is one of the important micronutrients that should be available to the plants. *Bacillus sp.* (Zn solubilizing bacteria) can be used as bio-fertilizer for zinc orin soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate ($ZnCO_3$) and zinc sulphide (ZnS) instead of costly zinc sulphate (Mahdi et al., 2010).

Potassium solubilizing bio-fertilizers: Potassium in the soil occurs mostly as silicate minerals which are inaccessible to plants. These nutrients are made feasible only when they are gradually weathered or solubilized. The decomposition of silicates is caused by organic acids which are produced by Potassium solubilizing microorganisms that solubilize silicates and helps in the removal of metal ions thereby making them available to plants (Itelima et al., 2018). The examples include *Bacillus sp*. and *Aspergillus niger*.

Potassium mobilizing bio-fertilizers: Some phosphate solubilizing bio-fertilizers that mobilize K and also solubilize P are *Bacillus sp*. and *Aspergillus sp*. which work by mobilizing the inaccessible forms of K (silicates) in the soil (Itelima et al., 2018).

Sulphur oxidizing bio-fertilizers: Sulphur is extremely important in the growth and development of plants. The application of sulfur coupled with thiobacilli renders alkali soils fit for the cultivation of crops. The formation of sulfuric acid by *Thiobacillus* in soil following additions of elemental sulfur augments nutrient mobilization by increasing the level of soluble phosphate, potassium, calcium, manganese, aluminum and magnesium (Sharma et al., 2012).

Silicate solubilizing bio-fertilizers: During the metabolism of microbes, several organic acids are produced and these have a dual role in silicate weathering. They supply H^+ ions to the medium and promote hydrolysis and the organic acids like citric, oxalic acid, Keto acids and hydroxy carbolic acids which form complexes with cations, promote their removal and retention in the medium in a dissolved state (Kumawat et al., 2018).

Plant Growth Promoting Rhizobacteria (PGPR): Nitrogen Fixation and the control of pests and diseases of plants are also done by some other bacterium than those mentioned above like Pseudomonas*, Bacillus thuringiensis* and fungi like *Trichoderma viride* by colonizing the rhizosphere of many plants (Ramasamy et al., 2020). Plant growth-promoting rhizobacteria (PGPR) are those bacteria which colonize roots or rhizosphere soil and are beneficial to crops.

These bacteria generally influence growth via P solubilization, nutrient uptake enhancement, or plant growth hormone production (Ritika et al., 2014). Plant Growth Promoting Micro-organisms (PGPM): Plant Growth Promoting Microorganisms (PGPMs) can be found in the rhizosphere, a dense, narrow and nutrient rich zone of soil located nearby the plant's root. It is characterized by the presence of different root secretions and intense microbial activity. Several plant hormones, siderophores, cyanides and lytic enzymes are produced by these microorganisms which have a phyto-stimulant effect on the plant and act as bio-pesticides and rhizomediators (Stamenković et al., 2018).

4.2 Advantages of bio-fertilizers

Biofertilizers play an important role in improving the fertility of the soil. Biofertilizers reduce the sole use of chemical fertilizers as their application improvises the structure of the soil Ritika and Utpal, 2014). It can be considered as a safe alternative to chemical fertilizers as it minimizes the ecological disturbance and is economical, eco-friendly, and can be produced in farm easily when needed in large quantities (Editor and Pradesh, 2019). The advantages of application of biofertilizers to maintain sustainable agriculture are:

- It increases the crop yield making soil enriched with the essential nutrients and micro-organisms needed for proper growth of the plants.
- Bio-fertilizers help in fixing atmospheric nitrogen into the soil and root nodules of legume crops and make it available to the crops.
- Hormones and anti-metabolites produced due to the action of biofertilizers promote the root growth and make the plants stress-resistant.
- The soil free of chemicals retain its fertility status and also makes environment free of pollutants and protect the plants from diseases.
- The yield is observed to be increased by 10 to 25% when bio-fertilizers are applied in seed or soil as it boost the availability of minerals without adversely affecting the soil and plant environment (Editor and Pradesh, 2019).
- Effects of bio-fertilizers on bio-remediation of metals: When heavy metal ions are present in elevated levels in the environment, plant root rapidly absorbs and translocate to shoot and leaves which cause stress leading to disturbed metabolism, reduced growth, and even plant death. The researchers have found that different microorganisms play an important role in the remediation of heavy metal toxicity (Mahanty et al., 2017).
- White Biotechnology: Employing live fungi or fungal enzymes for industrial applications is known as fungal white biotechnology. White biotechnology also uses living organisms as cell factories preferably utilizing renewable natural resources such as lignocellulose for production of a variety of materials and bio-compounds with energy efficiency, increased productivity, and environmentally sustainable characteristics and Fungal white biotechnology brings down greenhouse emissions which is eco-friendly in nature (Yadav et al., 2019).
- Bio-Transformation: Microbial biotransformation is widely used in the transformation of various pollutants or a large variety of compounds including hydrocarbons, pharmaceutical substances and metals and can be grouped under the categories: oxidation, reduction, hydrolysis, isomerization, condensation, formation of new carbon bonds, and introduction of functional groups (Ms et al., 2017).

4.3 Carriers for bio-fertilizers formulation

The choice of carrier depends on the desired viability of microorganisms as well as on the type of application (liquid, powder or seed coating) (Stamenković et al., 2018). Khosro and Yousef stated that the incorporation of microorganisms into carrier materials enables easy handling, long term storage, and effectiveness of the bio-fertilizer (Khosro and Yousef, 2012). A good carrier material must have the following characteristics:

- It must be easy to sterilize by autoclaving or gamma irradiation.
- It must be easy to process and must be free of lump-forming materials.
- It must be non-toxic to both the microorganisms and the plants, to which it is applied.
- It must have a good water retention capacity of more than 50%.
- It must have good pH buffering capacity.

Examples of carrier material include sawdust, talcum dust, manure, earthworm cast (Editor and Pradesh, 2019). Carriers which are used for making the solid type of bio-fertilizer products are clay mineral, diatomaceous soil, and white carbon as mineral; rice, wheat bran, peat, lignite, peat soil, humus, wood charcoal and discarded feed as organic matter (Ritika and Utpal, 2014).

4.4 Potential use of soil microbes in sustainable agriculture

The beneficial soil micro-organisms sustain agricultural production either as bio-fertilizers or symbiont. They carried out the task of nutrient solubilization which facilitates nutrient availability to the plants. It improves plant growth by advancing the root architecture. Their activity provides many useful traits to plants like increased root hairs, nodules and nitrate reductase activity. Efficient strains of Azotobacter, Azospirillum, Phosphobacter and Rhizobactercan provide an ample amount of available nitrogen through nitrogen cycling. The bio-fertilizers produce plant hormones, which include Indole Acetic Acid (IAA), Gibberellins (GA) and cytokinins (CK) and improve photosynthesis performance to increase plant tolerance to stress and increase resistance to pathogens thereby resulting in crop improvement (Bhardwaj et al., 2014).

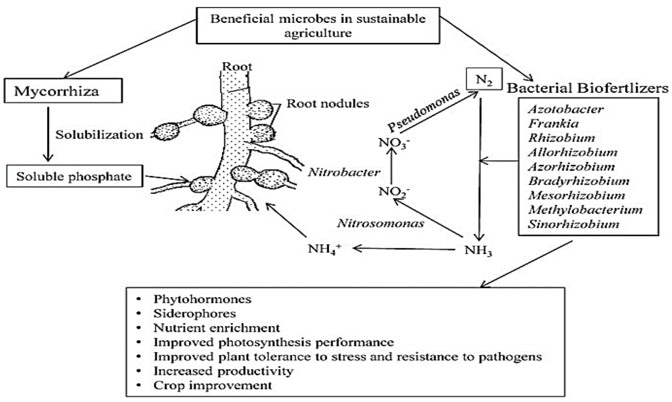

Figure 3: *Fixation of nutrients like Nitrogen, Phosphorus in legume crops via root nodules. Microbes like Nitrobacter, Nitrosomonas, Pseudomonas are fixing nitrogen in crops. On other side, Mycorrhiza is seen to be fixing Phosphorus* (Source: Bhardwaj et al., 2014).

5. Nodulation

Plant roots produce various organic compounds into the soil, a number of which permit microorganisms to grow within the rhizosphere and consist of carbohydrates, amino acids, organic acids, vitamins and phenolic derivatives. The main kind of signal from the plant to the bacterial partner is species-specific flavonoid type molecules, either in root exudates or released from the seed coat during germination, function as specific inducers or inhibitors of the nodulation genes in compatible rhizobia. A bacterial signal molecule (Nod factor) is crucial for induction root hair deformation and nodule formation. Exopolysaccharides, plant hormones, and vitamins are considered as regulators of the nodulation process additionally to key regulatory molecules (Bashandy et al., 2019).

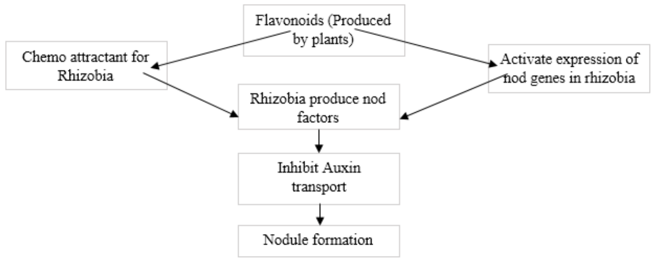

Figure 4: Summary of processes involved in nodulation (Source: Rhizobium nodulation and evolution (2013)/ (microbewiki.kenyon.edu)

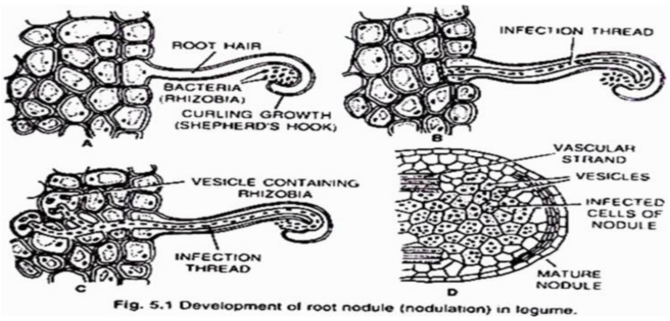

Figure 5: Nitrogen fixation (Source from: qforquestions.com)

5.1 Effects of Bio-fertilizers for Agricultural Practices

The steady rising trends of urbanization, industrialization, and an expeditious advancement in technology have turned out to be one of the notable challenging factors for agricultural development. This resulted in diminishing the fertility status of the soil, productivity of crops even by in-securing the future of food-producing ability of the Earth. According to FAO, the world population is assumed to rise upto 10 billion by 2050, rising agricultural demands. Concepts on Nature-Based Solutions are evolving significantly among agro-based workers from rural to urban areas with the aim to bring transformative change in farming so as to produce foods in a sustainable manner. While looking at various nature-based solutions for the agricultural sector; bio-fertilizers are getting popular worldwide to nurture all basic foundations of the agricultural world.

Bio-fertilizers prove to be a promising solution for regulating supportive conditions in agriculture, especially for crops susceptible to insect pest attacks that can result in a decline of crop production (Bisht et al., 2016). As per the present situation, fertilizer demand for agricultural crop production is much higher than the availability in the global market. According to a study to achieve the targeted production of food grain which is 280 MT by 2020, which asks for plant nutrients supply of 28.8 MT, but the market seems able to supply only about 21.6 MT of than that the demanded amount being a deficit of -7.2 MT (Bisht et al., 2016). Contradictory to the side-effects of chemical fertilizers, application of bio-fertilizers in the fields is proven to be environment-friendly, economically affordable with a few detrimental ecological effects, that's why bio-fertilizers are chosen as an ideal material to intensify sustainable agriculture principles (Bashandy et al., 2019).

5.2 Micro-Organisms Used in Bio-Fertilizers

The organisms used in bio-fertilizers as their components contain Nitrogen fixers, Potassium solubilizers, Phosphorus solubilizers and mobilizers, which are either used solely or together with fungi as symbionts as bio-fertilizers (Itelima et al., 2018). Amongst everything, the main thing to understand about the symbiotic association of plant roots with various bio-fertilizers along with mycorrhizae is that they play a mutualistic role with one another and perform variable of beneficial acts for plants, physical soil structure, on nutrient soil bank and so on; in order to mention any the ability of mycorrhizal fungi to convert insoluble phosphate into soluble form by forming organic acids, which lowers the soil pH and bring about the dissolution of bound forms of phosphate (Itelima et al., 2018).

5.3 Effects of Bio-fertilizers to enhance plant tolerance to environmental stress

To define stress, it refers to an occurrence or stimulus that needs us to alter in some ways. Environmental stress is termed as a negative pressure or deviation on the environment caused by various factors either by human activities (such as Pollution, Deforestation, etc.) or by natural events (such as the occurrence of drought, volcanic eruption, etc.). There can be various stress factors affecting the productivity of crops i.e. Biotic and Abiotic both, where biotic factors are often included as, the presence of predators, infection with pathogenic organisms or interactions with conspecifics, as well as abiotic factors like temperature, water availability and toxicants.

5.3.1 Phytohormones Secretion for Regulation of Stress

Phytohormones are natural organic compounds that enhance the growth and productivity of cultivars at fewer concentrations. The rhizosphere micro-organisms are observed to noticeably modulate endogenous phytohormone levels within the host plants, either by averting or producing them, to attenuate the negative effects by the environmental stress whenever plants encounter any growth-limiting environmental stresses (Mahanty et al., 2017). Out of the various environmental stress conditions that are known, there are numbers of experiments over a number of micro-organisms that are used as bio-fertilizers to cope with the stress conditions and enhance production. *Pseudomonas* spp. and other Rhizobacteria are well-known for their ability to colonize the root tissues of wide crop plants and promote the plant growth by the production of phytohormones, antagonistic substances and enzymes (Zulfikar Ali et al., 2011).

In order to mention some of them, have found that NaCl-tolerant Rhizobacteria can produce significant numbers of plant growth regulators (PGRs) like IAA, GA, CK, etc (Yadav et al., 2020). promoting the numbers, length of roots and root tips, that leads to the supplement of nutrients uptake by host plants in order to complementary maintain plants' fitness under saline conditions. Apart from this experiment, *Azotobacter* also has been seen to synthesize IAA, Gibberellin and Gluconic acids in some considerable amounts that also support the growth of plant roots to uptake plant nutrients by mobilizing phosphate under stress condition (Mohamed et al., 2019). In some cases, micro-organisms have also been found to infect plants other than leguminous plants like rice e.g. *Rhizobium, Sinorhizobium meliloti 1021* that promotes the production of endogenous growth regulator level like osmotolerant IAA so as to extend sprouting and photosynthetic rates in rice (Yadav et al., 2020; Bhardwaj et al., 2014).

5.3.2 Growth of Plants under Hyper Saline Condition

Salinity of the agriculture soil is a serious issue worldwide where 20% of the tilled land over the world and 33% of irrigated land, are salt-affected and degraded and is additionally a vital environmental factor for the reduction of growth and yield of agricultural crops. The density of more salt available in soil may alter the physiological and metabolic activities in the agricultural crops and reduce the growth and production of crops in both qualitative and quantitative ways (Manuel et al., 2017; Yadav et al., 2020). There are multiple reasons for the increase of salts in the soil, where the application of fertilizers is also one of the major contributors to the issue. And, in order to combat this problem, bio-fertilizers are taken as a potent solution as they act variably for soil health enhancement, by fixing atmospheric N_2, solubilizing insoluble soil phosphates and stimulating production of PGRs (Manuel et al., 2017). Among them, PGPRs, including endo- and ecto-mycorrhizal fungi, and many other useful microscopic organisms that led to improved nutrient uptake, plant growth, and plant tolerance to salt stress, are seen as potential microbes as they can tolerate various atmospheric conditions, as saline conditions being one of them (Manuel et al., 2017; Yadav et al., 2020).

Numbers of micro-organisms are found to be halo-tolerant. Gram-Negative Bacteria, *Swaminathania salitolerans,* bacteria belonging to the genus of *Azospirillum, Klebsiella pneumonia, Bacillus, Enterobacter, Rhizobium* and *Azotobacter. Azotobacter, Azospirillum,* PGPRs are some of the microbes falling under active halo-tolerant groups which are found to be effective for increasing root colonizing properties that assist for vegetative development, reproductive development and even yield increment over wide varieties of plants ranging from agricultural crops including vegetable crops like tomato, lettuce, pepper, bean, onion to leguminous crops like mung bean, to even mangrove plants even if they are irrigated with saltwater, as by enhancing or alleviating tolerance capacity of host plants, or by increasing fixing capacity (Yadav et al., 2020). An increase tolerance of *Medicago truncatula* against salt stress was also observed in plants nodulated by IAA – overproducing strain *Sinorhizobium meliloti* DR – 64 (Kim et al., 2012).

5.4 Drought Tolerant ability of Microbes

A drought is a reduction in precipitation over an extended period. This leads to a water insufficiency that damages crops, livestock, and the environment. Frequent occurrences of drought condition are the phenomena resulted from climate change in the world that is resulting in number of deleterious consequences on agricultural productivity status. In order to sustain the sound agricultural industry in the long run, the discovery and implementation of efficient management strategies of drought should be mandatory (Yadav et al., 2020). PGPMs are found to invade over the pleotheric level of the various endogenous mechanism of many host plants in order to modulate different reactions collectively with PGPRs necessary to overcome repeated drought events by enhancing nodulations process, fixation process (Yadav et al., 2020).

With the regular scientific study and understanding of the synergetic relationship between micro-organisms and agricultural crop plants for over years generation after generation, they are seen to develop beneficiary evolved traits to cope up stresses like heterogeneous approaches that include metabolic reprogramming, epigenetic plasticity and other such phenomena (Kerry et al., 2018; Naylor and Coleman-Derr, 2018). Microbial communities including Rhizobium and endophytic bacteria or mycorrhizae contribute to processes such as bioremediation, bio-augmentation, biotransformation, phyto-stimulation and biofertilization to soothe many devastating impacts over agricultural crops (Kerry et al., 2018).

5.4.1 Bio-remediation

Bio-remediation is a process used to treat contaminated media, including water, soil and sub-surface material, by altering environmental conditions to stimulate the growth of microorganisms and degrade the target pollutants. Some examples of bio-remediation bacteria with drought-resistance activity such as *Rhodococcus erythropolis, Acinetobacte johnsonii, Micrococcus luteus, Methylobacterium extorquens*, *Azospirillum,* etc. Many other PGPRE that promote plant growth and tolerance, namely *Acinetobacter* sp., *Arthrobacter* sp., *Alcaligenes* sp., *Azotobacter* sp., *Azomonas* sp., *Bacillus megaterium*, *Beijerinckia* sp., *Burkholderia* sp., *Enterobacter sakazakiia*, *Erwinia* sp., *Flavobacterium* sp., *Gluconacetobacter diazotrophicus*, *Herbaspirillium seropedicae*, *Klebsiella* sp., *Methylobacterium mesophilicuma*, *Paenibacillus odorifer*, etc.

5.4.2 Bio-augmentation

Biological augmentation is the addition of archaea or bacterial cultures required to speed up the rate of degradation of a contaminant. A typical bio-augmentation product actually comprises of a mixed multiple strain of microorganisms, most commonly bacteria or fungi isolated from nature without any genetic alteration within them. Some of the examples are *Pseudomonas putida* PD1 and *Salix alba*, Burkholderia sp. HU001; *Pseudomonas* sp. HU002 and *Salix viminalis* cv Tora, *Burkholderia cepacia* G4, *Lupinus leteus* etc. According to the action of bio-augmentation can sometimes alter as per types of soil i.e. effective in loamy sandy than that of sandy loam but still their various action for plant growth promotion will always prove to be highly beneficial for drought stress (Kerry et al., 2018; Baćmaga et al., 2017).

5.4.3 Bio-accumulation

Bio-accumulation construes the accumulation and enrichment of contaminants in organisms, relative to that in the environment. Bioaccumulation is the consequence of uptake and loss processes, like respiratory and dietary uptake, and loss by egestion, passive diffusion, metabolism, transfer to offspring and growth (Borgå et al., 2013). *Aspergillus niger*, *Rhizopus arrhizus*, *Aspergillus* sp., *Micrococcus* sp., *Alternaria* sp., *Fusarium* sp., *Geotrichum* sp., *Monilia* sp., *Penicillium* sp., *Rhizopus* sp., *Trichoderma* sp., *Aspergillus flavus* etc. are some of the microbes applied for this purpose. Some of the reports have also mentioned how indigenous microbes can be used usually for bio-accumulation remediation likewise use of *Piriformospora indica*, an endophytic fungus in symbiosis with *Oryza sativa* roots to transform arsenic salt into insoluble particles that render plant tolerance to drought (Mishra et al., 2013; Kerry et al., 2018).

5.4.4 Bio-Transformation

Biotransformation is a generalized biochemical transformation of foreign compounds/contaminants by bacteria or biological means without complete alteration of their stereochemistry or stability by living organisms. One of the important things mentioned by regarding the biotransformation is that it can occur both in aerobic (oxic) and anaerobic (anoxic) conditions, and has supported it by doing research that shows a wide range of bio-transformation over xenobiotic chemicals in those conditions (Speight et al., 2018; Smitha et al., 2017). *Bacillus, Pseudomonas, Escherichia, Rhodococcus, Gordonia, Moraxella, Mic rococcus* are members of the aerobic genera while the anaerobic types include *Methanospirillum, Pelatomaculum, Syntrophobacter, Desulfotomac ulum, Syntrophus, Desulfovibrio* and *Methanosaeta.*

6. Effects on Soil Health and Soil Productivity

Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. Soil is a dynamic body, and an important resource that functions to produce food and fiber to meet human needs and also functions on delivering to global balance and ecosystem function; or in essence, to the sustainability of life on earth. The quality of soil is an unprecedented necessity for sustainable agriculture. But the unhealthy competition of human beings to intervene in soil processes without any management practices is hindering agricultural ecosystem equilibrium, and altering mechanisms of soil. Since the voice for sustainable management of soil health with controlled human interventions is rising up; various practices to encourage natural functions and systems in the soil is being introduced.

Over the years of various researches and experiments done in order to understand the co-evolutionary relationship between microbes such as *Azotobacter, Azospirillum, Cyanobacteria, Mycorrhizae* and soil body, have shown that the soil bio-diversity has numerous advantages over soil's functions and regulations supporting the increment and rejuvenation of soil's quality and productivity even after adverse effects of stresses (Kibblewhite et al., 2008; Bhardwaj et al., 2014). Plant Growth Promoting Rhizobacteria (PGPR) have also been reported to support primary and secondary successions in many cases because of its ability to increase nodulation in plants and increase the fixation and absorption of nutrients like Nitrogen, Phosphorus (Chaparro et al., 2012). Apart from that role, PGPR and other biological have also been used to fight back pathogens by developing antagonistic modes of action as they are capable of producing antibiotics like lipopeptides, polyketides, etc. (Backer et al., 2018). Mycorrhizal fungi make the plant to draw more nutrients from soil with the help of extra-radical hyphae and the same thing even supports the aggregation of soil that contributes on one side for the improvement of soil quality, better tolerance of stresses, and also supports for quality plant health, sound yields (Johansson et al., 2004).

7. Effects on Crop Productivity and Plant Growth And Development

The inclusion of bio-fertilizers in soil plays a crucial function in bettering soil fertility by improving the nutrient availability to plants and impart better health to plants and the soil, thus increasing crop yields in an exceedingly moderate way (Yadav and Sarkar, 2019). Efficient strains of *Azotobacter, Azospirillum, Phosphobacter* and *Rhizobacter* can offer a significant supply of nitrogen to *plants* and to increase the plant height, number of leaves, stem diameter percentage of seed filling and seed dry weight (Bhardwaj et al., 2014). *Azolla* application brought an impressive increase in rice yield by 0.5-2t/ ha-1. *Azotobacter*, a free-living and heterotrophic bacteria fixes approximately 20 to 40 kg nitrogen ha^{-1} and increases yield up to 50% (Yadav and Sarkar, 2019). AM fungi play an important role in water regulation. Combined seed treatment of flax with nitrogen-fixing bacteria (*Azotobacter* sp. and *Azospirillum* sp.) along with phosphorus solubilizing bacteria including Bacillus sp. enhance the production of growth-promoting substances which help the multiplication of plant cell and cell enlargement and eventually increase all growth parameters (Yasin et al., 2012).

8. Effects on Plant Protection Against Pathogens and Insect Pests

The comprehensive examination of soil provides ideas on the context of soil microbiology, as the soil is a habitat that shelters millions of living organisms. Soil organisms can differ from micro-organisms like bacteria, viruses, fungus, protozoa, actinomycetes to nematodes, earthworm. Collectively, soil organisms are a requisite part of our soil ecosystem that plays an essential role in the decomposition of organic matters, nutrients cycling and soil fertility. With the integrated role among the soil communities, they contribute as a key role in the sustainable maintenance of human civilization and other lives on the planet. However, no all microbes in soil are helpful, soil is also a reservoir for pathogenic microbes. Those pathogenic microbes can influence crop productivity, soil's structure resulting in crop loss, soil infertility and much other soil's mechanisms (like nutrient recycling). Bio-fertilizers are auxiliary elements to soil and crop management traditions viz., crop rotation, organic adjustments, tillage maintenance, recycling of crop residue, soil fertility renovation and the bio-control of pathogens and insect pests, which operation can substantially be expedient in upholding the sustainability of various crop production (Bhardwaj et al., 2014).

Results from contemporary analyses reveal that the action of specific soil micro-biome may have a momentous role in defeating soil-borne pathogens and lastly result in the development of the soil system resilience (Wang et al., 2019). AM fungi have the propensity to lessen impairment caused by soil-borne pathogenic fungi, nematodes, and bacteria. It was testified that plant diseases induced by the pathogens like *Fusarium* spp*., Pythium* spp., *Rhizoctonia* spp., and *Sclerotium* spp., can be treated by applying biofertilizers such as *Trichoderma harzianum*, *P. fluoresecens*, and *Bacillus subtilis* which improves plant growth and total yield (Mahanty et al., 2017).

9. Induced Systemic Resistance (ISR)

The phrase "induced resistance" is a generic term for the induced state of resistance in crops activated by biological or chemical inducers, which safeguards non-exposed plant parts against possible attacks by pathogenic microbes and herbivorous insects. The interaction between some *Rhizobacteria* and plant roots can block pathogenic fungi, bacteria, and viruses from damaging the host plant. This phenomenon is known as induced systemic resistance (ISR) (Mahanty et al., 2017). *Pseudomonas, Bacillus*, and *Trichoderma* strains usually instigate an auxin-dependent root developmental program that leads to profuse lateral root formation, increased root hair length, and better plant biomass production (Pieterse et al., 2014). An example of recruitment was exhibited on infection of foliar parts of Arabidopsis by pathogenic *P. syringae* (Pieterse et al., 2014).

10. Effects on Ecosystem

An ecosystem is an intricate network between all the biotic and abiotic components in nature. Bio-fertilizers, being eco-friendly, cheaper, and convenient to use for higher yield, is becoming popular among alternative choices to transform the agriculture sector by integrating with different biotechnological tools. Microbes used in bio-fertilizers are advantageous as based on their own characteristics they alleviate nutrient bank of soil and facilitates in maintenance of clean water-balance. Bio-fertilizers can even help in refurbishment of nutrients, water level and helps in revival and revitalization of new ecosystems under the nature of microbes of bio-fertilizers.

11. Challenges for Using Biofertilizers

According to a study, when compared to inorganic fertilizers the most important constraint of bio-fertilizer is its nutrient content which leads to failure in development of plant (Mahanty et al., 2018). Moreover, lack of proper carrier material, vulnerability to rise in temperature, short shelf-life, complication in transportation and storage of bio-fertilizer are compulsion to be solved in order to achieve productive inoculation (Chen et al., 2006). The most challenging part for the research involves addressing the mechanism of bio-fertilizer along with the identification of numerous strains and their respective properties. Due to a number of challenges, there is no operative implementation of biofertilizer in the field that are confronted in the production and implementation of these bio fertilizers (Ritika and Uptal, 2014). Some researchers broadly classified these constraints into four types (Kumari et al., 2019):

- ***Production Constraints***: the absence of suitable and effective strains, the unavailability of appropriate carriers and mutation during fermentation.
- ***Market Level Constraints***: lack of cognizance, proper quality, inexperienced staff, etc.
- ***Resource and quality Constraints***: infrastructural constraints such as inaccessibility of essential equipment, power supply, etc.
- ***Field Level Constraints***: soil conditions, native microbial population, faulty inoculation.

As well, also acknowledged various considerable challenges faced in judicious application of bio fertilizers. Some of them are (Kumawat et al., 2018):

- **Financial constraints** like lack of sufficient funding and uneasiness in getting bank loans.
- **Environmental constraints** like seasonal demand for bio-fertilizers, simultaneous cropping operations and short span of sowing/planting in a particular locality, etc.
- Lack of knowledge on the benefits of the technology due to constraints in adoption of the technology by the farmers due to different mechanisms of inoculation, no visual difference in the crop growth immediately as that of inorganic fertilizers.

Thus, all of these different constraints in one way or the other affect the technique at production, or marketing or usage of the bio fertilizers.

12. Scope of Biofertilizers in Organic and Sustainable Agriculture

Rapid over-exploitation of non-renewable natural resources can generate a food crisis in forthcoming years. The agricultural crop production is critical to be intensified without worsening the quality of the environment. Organic agriculture has now been topmost priority across the globe in view of the growing demand for safe and healthy food along with long term sustainability. The application of biofertilizers has procured much acceptance, especially in developed countries due to the ecological impacts related to overuse of synthetic chemical fertilizers in farming. It is proclaimed that if we are able to establish inert material that can rise the stability of biofertilizer products, elongate its life span, it will result in greater implementation of biofertilizer in future (Abhilash et al., 2016). The success related to bio-fertilizers depend upon innovative strategies associated with the proper implementation of beneficial bacteria.

The application of biofertilizers in preference to chemical fertilizers is the best alternative choice. Different studies have encouraged to utilize PGPRs as a biofertilizer (Bashandy et al., 2019). All the researchers of agriculture conclude the simple fact that biofertilizers are the best choices for the big picture where they would prove to be the best option to take for sustainable agriculture. The diminished impartation of noxious chemical compounds is directly favorable for the environment in the instant sense of use but that is not all of it. Extensive ranges of microorganisms have different actions on plant growth through increasing the availability of nutrients (N, P, K and Fe) and facilitate their uptake by plants. Plant growth-promoting rhizobacteria can also protect plants from pathogens and make them able to sustain in several brutal situations (Bashandy et al., 2019). The biofertilizers are advantageous both for the environment and for the plants that we use these biofertilizers on. If the appropriate studies are carried out and microorganism can be recognized for the brutal soil situation, the yield can also be raised in those areas. Some researchers also said that with the use of biological and organic fertilizers, a low input structure can be carried out, and it can be helpful in the sustainability of farms (Khosro and Yousef, 2012).

The use of biofertilizers is not merely beneficial to the environment. It also has benefits for the plants themselves alongside providing a boost for the economic development of sustainable agriculture. The use of biofertilizers profoundly lessen the economic burden on the producers and farmers and hence strengthen the economic model as a whole in the field of agriculture. Alongside this, it also sustains the ecological cycle and help to maintain the well-being of it. Thus, as a whole, the use of biofertilizers will help in the comprehensive development in the area of sustainable agriculture.

13. Organic 3.0 Concept and Biofertilizers

Precedence has been given to organic farming for dealing with the complications arising in Agri-farming by many organizers and researchers. The term Organic 3.0 was coined in Germany, 2010 (Strotdrees et al., 2011). This development is explained (Arbenz et al., 2017). Organic 1.0, Organic 2.0 and Organic 3.0 are different changes in phase which has gone through the organic sector. Organic 1.0 is defined as the period of organic pioneers, developing the vision of organic agriculture (OA). Organic 2.0 is the period of growth and marketing of organic, which has taken place in recent history. Finally, Organic 3.0 addresses future challenges and aims at entering organic agriculture on the global stage. These definitions were adopted by the global organic movement (Rahmann et al., 2013; Arbenz et al., 2015; Rützler and Reiter, 2014; Niggli et al., 2015). Approved by our General Assembly in 2017, the overall goal of Organic 3.0 is to enable a widespread uptake of truly sustainable farming systems and markets based on the principles of organic agriculture. Organic 3.0 aims to solve challenges in the food chain such as healthy and affordable food for everyone, minimized environmental and food pollution, fairness for producers, high animal welfare, and efficiency in resource utilization, described the key features of Organic 3.0 (Arbenz et al., 2017):

- A culture of innovation,
- Continuous improvement towards best practice,
- Diverse ways to ensure transparency and integrity,
- Inclusiveness of wider sustainability interests,
- Empowerment from farm to the final consumer,
- True value and cost accounting.

The visions that have been formulated in Organic 3.0 can be fulfilled via the use of bio-fertilizers too. Bio-fertilizers consist of plant remains, organic matter along with some special biological efficient microorganisms. Bio-fertilizers are natural and don't cause any environmental harm and stress. It contributes to the improvement of soil's physical properties, fertility as well as productivity of the soil. This makes bio-fertilizer a necessary weapon for sustainable agriculture and sustainable environment.

14. CONCLUSION

Huge demand for food by the growing population has encouraged the industries to the manipulation of chemicals in the form of pesticides or fertilizers. These chemically manufactured fertilizers are hazardous for human health as well as contribute to disturbance of ecological balance. Bio-fertilizers are able to balance the shortcoming of chemical-based technology. Bio-fertilizers are capable of supplying sufficient nutrients to the plants along with increment in its productivity. The application of bio-fertilizers helps in the establishment of a low input farming system. Additionally, they address different environmental issues too. Extensive research in developing efficient and temperature tolerant strains would result in success of bio-fertilizers in future. There is an urgent need to improve awareness regarding the beneficial aspects of bio-fertilizers. Its proper implementation aid in maintaining long-term soil fertility. This non-destructive means of obtaining high yield will not only have an impact on the sustainability of agriculture but also put up to a sustainable ecosystem.

FUTURE RESEARCH WORKS

The authors recommend that future research endeavors should include indepth studies so that farmers can understand the role of biofertilizers and organic farming in maintaining sustainable agriculture. The present review can be applied to increase impart the knowledge and make crop growers literate. Future research work should be focused on the initiation of the programs regarding the sustainability of agriculture through organic farming which is environment-friendly, economical, non-toxic, and healthy. Training and extension programs in Nepal have been limited in scope. Initiatives such as extension services, seminars, and agricultural programs to make farmers educated on organic way of producing goods should be developed. It is hoped that the findings of this review present clear insights into efforts that will encourage farmers to precedence on organic farming and sustainable agriculture.

ACKNOWLEDGEMENT

We owe our sincere and deep gratitude to the parents whose guidance and support is always with us. Special thanks to Asst. Prof. Dr. Mukti Ram Poudel, Department of Plant Breeding, Paklihawa Campus, Tribhuvan University, for his constant support and valuable guidance for the completion of manuscript.

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