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ORGANIC FARMING: EXPLORATION OF ORGANIC AMENDMENTS AND BIOAGENTS FOR SUSTAINABLE AGRICULTURE

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ABSTRACT: *The satisfaction of increased yield obtained through applications of inorganic fertilizers and pesticides had beclouded many of the inherent dangers chemical applications posed to agriculture and soil health through disruption of natural processes in the soil. Meanwhile the use of organic amendments and bioagents is environmentally friendly, sustainable, encourages biological processes and promotes healthy soil-plant relationship. Many bioagents (biological pesticides and botanicals) have been proven to confer resistance on plants against several diseases while soils that are rich in organic materials are loose, airy and hold more moisture and nutrients. Such soils foster better growth of soil organisms, and promote healthier plant root development. Therefore, the use of organic amendments and bioagents in lieu of chemical based applications needs to be encouraged across the globe towards promoting food security and safety. Hence, this review focuses on the potentials of organic amendments and bioagents for enhanced soil integrity and plant growth needed for sustainable agriculture.*

KEYWORDS: Inorganic fertilizer; soil-plant relationship, environmental friendly, food security, soil integrity, plant growth.

INTRODUCTION

Inorganic fertilizers are man-made chemical products which are applied to the soil for sustenance of plant growth. The uncontrolled and excessive use of chemical fertilizers such as urea which is the most common commercial fertilizer, usually alters the physical and chemical properties of the soil and reduces the activity of microorganisms in the soil (Asadu and Unagwu, 2012). Most synthetic fertilizers which contain sulfuric and hydrochloric acids have a tendency of altering the soil pH and adversely affect valuable flora/fauna while some others cause contamination of heavy metals (Asadu and Unagwu, 2012). Judicious use of mineral fertilizers requires soil testing in order to determine the correct amount and kind of fertilizer to

apply to crops. Soil testing however is costly and inaccessible to most farmers, especially in the developing world. Many mineral/inorganic fertilizers are expensive for farmers in developing countries to apply the recommended application rates, while many who can afford them use wrong formulations and quantity (Usman et al., 2015).

Organic fertilizers are plant and animal-based products applied to soil in order to support plant growths. Organic fertilizers also create a favorable soil environment in which valuable macro and micro flora and fauna thrive. It as well enhances the soil's inherent buffer capacity and do not lead to contamination by heavy metals. Whereas, organic amendments are composts derived from decaying plant, animal or their products which are applied to the soil for enhanced fertility. Biopesticides on the other hand refers to living organisms or their products that can be utilized for the control of plant's pests or diseases while bioagents are living microorganisms that can either enhance the plants growth or their resistance to diseases/pathogens. Hence, exploration of these three entities would be the preferred alternatives in place of chemical products in ensuring for food security and sustainability in agriculture.

The gradual release of nutrients from organic fertilizer ensures continual supply for plant uptakes and over the years, the addition of organic fertilizer increases organic Nitrogen (N) and Sulphur (S) content in the soil (McNeill et al., 2009; Asemoloye et al., 2017a). Meanwhile, the challenge of equitable distribution of nutrients through prevailing organic fertilizer/manure management methods could be addressed through refining methods used to process large quantities of organic wastes (McNeill et al., 2009). Many populations of beneficial soil microbes like rhizosphere fungi and nitrogen fixing rhizobia bacteria have been reported to support the growth of crops and their resistance to diseases.

Roles of bio-resources in promoting the soil integrity and fertility

Bioresources as principal components of the soil

Bio-resources are non-fossil biogenic materials which can be applied by humans for several purposes such as food, essential products, and/or energy. Bioresources be it Primary (crops, algae, fungi, bacteria and other soil organisms), Secondary (by-products or residues of biological organisms or green areas), or Tertiary (parts of virgin materials separated from processing chains) bio resource are naturally available or applied by humans in the soil playing significant roles in the soil. Unfortunately, little attention has been focused on the optimization of soil biotic component from the perspective of soil integrity (Asemoloye et al., 2017a and b). Soil is made up of several components, the solid phase comprises diverse mixture of inorganic (40-45 %) and organic components (5 %) while water and air make about 50 % volume of soil. This however depends on the amount of vegetation, soil compaction as well as water availability but all these defines a good healthy soil that can promote and sustain plant life. It is also notable that the soil is a pore network containing physical and primary habitat for all soil organisms, it is regarded as the 'Biological engine of life' an inner space that houses all belowground life and functions (Ritz, 2008).

The importance of soil is unquestionably verse and it needs to be maintained and managed in a sustainable way. The factors which contribute to effective soil fertility are diverse and complex (Mader at al., 2002) but the soil biota have been known to contribute immensely to effective soil functions especially in the maintenance of agricultural fertility (Kibblewhite et

al., 2008). The biomass is although a small proportion of total soil mass but has the greater effect on its functions. According the Jenkinson (1977) the biomass is predominantly the biological constituent of the soil called 'needle eye' through which all organic materials pass. The biomass constitutes the biological components that entirely interact in a series of complex mechanisms for recycling nutrients and ensuring continual soil function.

Roles of bioresources in the enhancement of soil integrity

The un-uniform structure of the soil creates a heterogeneous porous matrix that serves as habitat for the soil organisms. These conform to an 'aggregate dynamic model' of Six et al. (2002) which often influence the organic inputs. The influence of microbiota on the soil structure can be direct or indirect including the movement and alignment of primary particles along the cell or hyphal surfaces, adherence of particles due to adhesive force produced by the colony cohesion, metabolites or exudates like extracellular polysaccharides, the coating of pore walls with hydrophobic compounds such as fungal mycelium insulating polymers and enmeshment and binding of growth structures such as fungal hyphae or mycelium. There are different key factors that define an ecosystem service of soil biota, the soil structure integrity, carbon cycling, nutrient cycling, biotic regulations and so on. Soil itself was a product of series of biogeochemical transformations such as weathering and it is made up of different components such as clay, silt and sand fractions respectively. The mineral components of the soil together with organic materials aggregated to larger unit bind together to form larger scale as part of the soil structure in a hierarchical scale.

The soil structure can also be influenced by microorganisms due to their actions on the organic materials. The organic matters as potentially energy containing substrates serve by binding the soil particles together, their degradation by microorganisms often disturbs the soil structure and loss in soil carbon (Conant et al., 2007). The interaction between water, microbial activities and pore network in the soil is fundamentally linked with the matric or profile of the soil. Microbes such as protozoa and bacteria need water film to move, fungi can extend to large surfaces through their hyphae or mycelium which can penetrate air filled pores. Microbes have developed diverse survival mechanisms such as aerobic or anaerobic respiration for surviving different soil processes like methanogenesis and denitrification.

The soil organic matter is gotten from primary producers of terrestrial vegetation; this has verse influence on soil function and agriculture (Magdoff and Weil, 2004). The soil carbon is gotten from the photoautotrophs that carry out photosynthesis (organic matter). The above ground biomass (Plants) decay on soil as organic matters and constitute to the soil nutrients which are continuously transformed by a series of chemical and biochemical mechanisms majorly carried out by the soil biomass (Marschner and Romheld, 1994).

Soil organic matters are primary energy source for the soil organisms, the compounds released from them also are transformed and cycled around the soil compartments. For this to occur, soil organisms need to migrate to access the organic matters, this movement across the soil matrices and as a result contributes to the structural soil development and buffering (Paul, 2007). Bio-perturbation can be considered as the genesis and maintaining force of the soil structure and function (Wilkinson et al., 2009). The invertebrate fauna like worms, ants or molluscs as well as the plants roots are often concerned with physical disturbance of the solid

soil matrices to gain passage and locomotion and by this they also ensure the mixing and distribution of substantial soil materials (Ussiri and Lal, 2009). The plants are the primary producers of fixed carbon; the microbial respiration balances the net ecosystem carbon flux (Schulze, 2006).

Organic amendments for enhancement of soil and plant health towards sustainable agriculture

Organic fertilizers in organic farming

The use of organic fertilizers/manures in appropriate amount augments the growth of crops, thus the productivity by having a good impact on the soil microorganisms and biological life in general, nutrients which are very present in manure are released slowly for plant uptake (Fig. 1). Although other minerals like Phosphorus and Nitrogen that are found in compost are not accessible to plants, they have to be transformed first into compounds that can be up taken by plants easily before the nutrients in inorganic form can be accessible and easily taken by crops; that accessibility is higher in the first year of application of organic fertilizers in the soil (Motavalli et al., 1989).

The use of compost however improves the physical and chemical properties of the soil as well as the soil structure and it increases the quality of the soil fertility by increasing nutrients, enhancing the pH and other metallic minerals will be decreased to an appropriate amount for plant utilization. Manure also improves the biological activity of the soil (Sommerfeldt and Chang, 1985). Manure requirements for many crops are generally ranged between 5 to 20 tons of fresh manure per ha. Nevertheless, the nutrient content of manure depends on many factors like the source of material used for compost and its mixture, the application technique and even the storage method (Harris et al., 2001). Research stations use more quantity of manure while farmers use less very often even if those farmers prefer manure as it is the case of farmers in Kenya; that preference is due to the fact that the organic manure last longer in the soil compared to the commercial fertilizer (Lekasi et al., 1998).

The purpose of organic farming is to have a balance between the interconnected system like humans, plants, animals and soil organisms. It is reported to be one of the fastest growing in the Agriculture sector across the world (Berova, et al., 2010). It is essential in the biological process of plants, help in the suppression of population of plant pests, increase anion and cation exchange potential, increase the microorganism activity, organic matter and carbon content of soil (Tonfack et al., 2009). Arancon et al. (2004) established that the organic fertilizers have the potential to increase the yield and quality of agricultural produce like inorganic fertilizers, although causes little or no damage to the environment. Its action of preventing diseases through which it meets the nutritional needs of plants as well as enhancing the plant tolerance removes a serious source of stress. Ogbalu (1999) reported the effectiveness of sawdust, spent grain, wood ash and rice bran as fertilizers which are readily available and accessible to farmers compared to chemical fertilizers.

Aside, increasing the quality and yield of plants, it enhances the chemistry, biological activity and structure of soil through the provision of nutrients which contribute to the soil quality. Sarkar et al. (2003) emphasized its gradual release of nutrients in organic compost which help in enhancing the quality of the soil.

Role of organic fertilizers in plants' immunity against diseases

Plant disease development can be affected by introducing fertilizer under field condition via plants' nutritional status and the conduciveness of the factors that favor disease development indirectly. Biofertilizer just like vermicompost play an essential as organic nutrient source for crop growth as well as sustainable soil health Mali et al. (2005). Fertilizer application time to time lower disease attack to plants because it helps plants to growth vigorously due to high absorption of nutrients and their plenty availability into the soil as leaching of organic fertilizers is less due to the fact that the nutrient uptake is high and they may last a long time in the soil. Whenever the plant is healthy, vigorous and robust it also becomes less susceptible to diseases as this helps the plant to develop essential adaptive structures such as thickening of cell walls and tissues as mechanical barrier against pathogens, this mean that their immune ability is outstanding under continuous supply of nutrients. Contrary to weak plants with hunger, malnourished plants are stressed and hence are less tolerance to disease attack (Panique et al., 1997). It is said that some plants are resistant to infections while climatic conditions can also affect pathogenicity.

Organic materials like manure, compost and organic residues may act as excellent alternative method to control pests and diseases because those materials increase activity of beneficial microorganisms which suppress soil borne disease and prolific of pathogens (Zaccardeli et al., 2013). It has been reported in several studies that organic fertilizers respond well to the development of potato dry rot as well as other diversity of fungi population which may cause the disease in store. So different forms of biofertilizers and cropping systems of cereals and legumes were used to test their effect on the dry rot disease then the results showed the significant difference. Huber and Graham (1999) reported the interaction of nutrients with suppressions of some plant diseases such as stalk rot of corn, *Verticillium* wilt, take-all of wheat, clubroot of crucifers, *Fusarium* wilt and *Streptomyces* scab of potato. Ling et al. (2010) also revealed the suppression of *Fusarium* wilt disease of watermelon by bio-organic fertilizer by fermenting mature compost with a mixture of *Paenibacillus polymyxa* SQR21 and *Trichoderma harzianum* T37 which are antagonistic organisms. Pascual at al. (1997) established the provision of balanced and timed source of nutrient to plant growth by organic amendment via slow decomposition of organic matter by microorganisms, mineralization and nutrient release. Ismail, (1997) reported that aside the micronutrients and macronutrients vermicompost contains, it contains plant growth promoting substances such as auxins, humic acids N-fixing and P-solubilizing bacteria, vitamins and enzymes. These water soluble components increase the availability of nutrients to plants which result to better output and good quality (Atiyeh, 2002).

The combined use of organic and inorganic fertilizers for improving productivity

The risks allied with sole use of either organic or inorganic fertilizers in crop production can best be addressed through combined application of organic and inorganic fertilizer. Absolute reliance on inorganic fertilizers could result in soil chemical and physical degradation while on the other hand sole reliance on organic fertilizer could be limited because of competing alternative uses of the organic materials, bulkiness thus referring to the volume required for optimizing crop productivity, asynchrony of nutrient release versus crop nutrient demand and biomass quality (Usman et al., 2015). According to Asemoloye *et al.* (2017a) a combination of organic and inorganic sources of plant nutrients in degraded soils is requisite for the sustenance and improvement of crop productivity. Combined use of synthetic fertilizers and organic

sources of nutrients usually culminate in increased crop yields (Opala, 2010). Synchrony between N release and crop nutrient demand can be attained through combined application of organic fertilizer and factory N and can reduce leaching of N (Kuntashula *et al.,* 2004).

Role of soil nutrients in plant defense

Soil nutrients are essential for plant growth and development hence their importance in plant disease control. Correct management of soil nutrients is a factor to be considered in plant disease management as plants need adequate nutrients to develop disease resistant. Although, resistance depends largely on the genotype of the plant but adequate nutrient availability also may go a long way in the control of disease caused by both biotic and abiotic agents.

Potassium deficiencies often cause the plant to be deficient in fighting some parasites due to metabolic malfunctioning. Under K-deficient condition, plants are less able to produce efficient protein synthesis, accumulate simple N-compounds such as amides and synthesize high molecular weight compounds such as thicker epidermal cells, cutin, and cellulose which are essential to fight invading pathogens. This also defines the fact that there must be balance in K to N ratio. Nitrogen on the other hand is very essential for plant growth and disease resistance, there are several reports on the effect of N on the plant physiology of plant diseases and its importance in disease control cannot be overemphasized. Phosphorus is essential to plant growth and it is an intrinsic part of many organic molecules, it is much involved in the metabolic processes in plants and in the pathogens. A number of other studies have shown that P application can reduce bacterial leaf blight in rice, downy mildew, blue mold, leaf curl virus disease in tobacco, pod and stem blight in soybean, yellow dwarf virus disease in barley, brown stripe disease in sugarcane and blast disease in rice.

Calcium is another important nutrient that affects the susceptibility to diseases in two ways. First, Ca is important for the stability and function of plant membranes and when there is Ca deficiency there is membrane leakage of low-molecular-weight compounds, e.g. sugars and amino acids, from the cytoplasm to the apoplast, which stimulate the infection by pathogens (Marschner and Romheld, 1994). Second, Ca is an important component of the cell wall structure as calcium polygalacturonases are required in the middle lamella for cell wall stability. When Ca concentration drops, there is an increased susceptibility to fungi which preferentially invade the xylem and dissolve the cell walls of the conducting vessels, which leads to wilting symptoms. In addition, plant tissues low in Ca is also much more susceptible than tissues with normal Ca levels to parasitic diseases during storage. Ca treatment of fruits before storage is therefore an effective procedure for preventing losses both from physiological disorders and from fruit rotting. Adequate soil Ca is needed to protect peanut pods from infections by *Rhizoctonia, Pythium* and application of Ca to the soil eliminates the occurrence of the disease. Other nutrients such as sulfur and magnesium, there is not enough information about their role in plant diseases. S can reduce the severity of potato scab, whereas Mg decreases the Ca content of peanut pods and may predispose them to pod breakdown by *Rhizoctonia* and *Pythium*. Organic fertilizers can enhance the soil profile, its chemical and physical properties and affect pathogen development.

Nitrogen fertilizer application was proven to raise plant's immune up to certain level as any given increment of nitrogen fertilizer induce plant defense. "Their primary and secondary metabolisms of the plants are reconfigured in response to pathogen infection, and these also

have the influence of N". The effect on the patterns of amino acid biosynthesis by nutrition regime affects gene expression, which include defense genes (Zhang, 2011). N levels have been reported to affect the production of polyphenolics under different N regimes and constitutive defense based on alkaloids (Johnson et al., 1987). The mineralized of organic matter with the help of microorganisms has a greater influence on availability of N into the soil for plant use. A clear example, ammonification of organic forms of N and further nitrification alter the availability of different N forms to the plant during its growth. However, nitrogen availability can influence disease development and plant resistance. For example, some research showed that black root rot disease symptoms on sugar beets and *Fusarium* wilt on tomato were severe where NH^{+4} fertilizer was applied, discovered by (Afanasiev and Carlson, 1942) and (Borrero et al., 2012), respectively. This was due to the high content of protein chains and sugars which come from the roots and diffuse into the whole plant cell walls and intercellular space therefore the nutrients become available abundantly to the invading pathogen.

Botanicals, and bioagents: alternatives to chemical pesticides and inorganic fertilizers

Botanical Pesticides

Botanical pesticides are plants or plant extracts that can be used as pesticides (plant biocides). Scientists and researchers developed pest controlling agents such as pesticides due to massive loss of agricultural crops and its financial consequences. The most significant problem globally for farmers is protecting their crops from pest attack. The economic losses and harmful effects of agricultural crops and commodities caused by pests is unquantifiable, hence the need for pest management in Agriculture. Globally, some percentage say 10-15% of the yield of commodities such as wheat, rice, potatoes and maize is lost due to pest invasion which has major effect on the economy of countries (Kandpal, 2014).

Conventional synthetic inorganic pesticides are the major sources of various environmental problems which include imbalances in the ecosystem, loss of soil fertility, and deterioration of marine life etc. The common synthetic inorganic pesticides also cause various harmful and serious issues on humans and animal health leading to severe cancers, neurological disorders, hormonal disturbances, and reproductive issues. The use of conventional pesticides is the most common practice however their toxicity is a source of worry to the health of the farmers, animals grazing on forage and to the consumers of the crops. Due to the negative effects of chemical pesticides on human health, there have been a series of calls and interest in the use of botanicals as pest control due to their eco-friendly characteristics and cost friendliness.

DDT which was the first pesticide was developed in 1939 and brought a wide change in pesticide research and the use of pesticide is governed by various guidelines in different countries of the world. Pesticides are majorly classified based on the following parameters: mode of action; target pests; and chemical nature (Fig. 2). The American Medical Association further classified pesticides into two namely, synthetic pesticide and biopesticide (Fig. 3).

Due to the persistent and destructive nature of chemical pesticides in the environment and also its effects on the health of humans, there have been several calls, actions and search for a substitute to chemical pesticides. Botanical pesticides are naturally occurring chemicals extracted or derived from plant materials. They are also called natural insecticides because they

are originally extracted from plants and not synthetically manufactured. Botanical pesticides obtained naturally from plant based chemicals have been found to be an effective alternative to usual pesticides (Kandpal, 2014)). For example, Neem based pesticides, pyrethrum, and Eucalyptus oil are few of the most important botanical pesticides used widely for agricultural pest management.

Bio-pesticides are one of the alternatives to chemical pesticides. They are biochemical in nature i.e. they have natural constituents which control pests by non-toxic mechanisms (Dutta, 2015). Biopesticides are obtained from natural materials such as plants, microorganisms and even from animals. Biopesticides can also be made from microbial byproducts, phytochemicals and living organisms. Kandpal, (2014) explained the beneficial characteristics of biopesticides to include: a) less harmful, b) eco-friendly, c) specific i.e. targets only a particular type of pest d) small dosage are effective e) biodegradable and non-persistent. Types of botanical insecticides include Alkaloid, Essential oils, Flavonoids, Glycosides (Rattan, 2010; Goławski, 2014).

Botanical pesticides: mechanism of attack against plant pathogens

Botanical pesticide as repellants possesses repellent characteristics that protects against insect pest, and guard the plants by arousing olfactory or other receptors (Talukder, 2006; Isman, 2006) with little or no impact on the environment which make them preferable and a good alternative to synthetic pesticides. Botanical pesticides have also been found to be safe in pest control because they have low or no pesticide residue unlike chemical pesticides which make them safe to people, especially farmers who use them regularly and preserves the ecosystem (Talukder et al., 2006; Akanmu et al. 2013; Aroge et al. 2019).

They can also act as feeding deterrents/antifeedants against plant pathogens, this they do by disrupting the hormonal balance or inhibit insect feeding by making the food which is the treated crop unpalatable and unattractive to them (Rajashekar et al., 2012). The insects will stay longer on the preserved crop but will not have access to any of its parts and eventually starve to death. Toxicity: Botanical pesticides can also be toxic to postharvest pests and cause death of some insects/pest affecting stored products (Padin, Fuse et al., 2013). For example, Rotenone a compound toxic to insects which acts as a mitochondrial poison by blocking the transport of electrons in the system thereby prevents energy production ultimately killing the pests (Padin et al., 2013). Qari, Nilly et al. (2017) in their work proved that damage occurred to the DNA due to disruption in enzymatic system and total protein concentration after application of botanical pesticides to stored products.

As growth delay and development inhibitors, botanical pesticides have also been shown to produce a harmful effect on the growth and development of insect pests by reduction in the weight of their larva, pupa and adult stage which will be a major setback for them to complete their life cycle on time and therefore reduce their performance (Talukder, 2006). Reproduction delay/ Sterility: This can be done by a chemosterilant or a method known as sterile insect technique (SIT). This is a substance that hinders the reproduction of sexually active organisms (Morrison et al., 2010). Chemosterilant act by initiating a temporary or permanent sterility to either sexes of crop pests or by inhibiting the development to sexual maturity stage of a young pest.

Botanical pesticides also act as chemosterilant by hindering the synthesis and discharge of hormones from the prothoracic gland which leads to sterility in mature insects (Isman, 2006). Sterility occurs based on the plant material used as a pesticide, the insect pest involved and exposure time. For example, the presence of volatile oil from certain plants has shown to block the tracheal respiration of insect pest which lead to their death. Essential oils act by blocking insect acetylcholinesterase (AChE) and thus, ultimately hindering certain nerve functions. Mikhaiel, (2011) reported that certain plant oils affect acetylcholinesterase (AChE) which also affected the nervous system.

Bioagents and their stimulatory effects on plant growth

Biogents are soil microorganisms that can stimulate the plant growths or aid their defense mechanisms through the root colonization. Some research has also found out some bioagents which have the ability to control a wide range of pathogens harbored by a single plant. The research discovered some biological control agents which had broad-spectrum activity to control multiple pathogens in a host plant effectively (Wang et al., 2010; Zhao et al., 2011; Huang et al., 2015). Two fold antagonistic bacteria defined as the bacteria from which a single species of bacteria reacts antagonistically to two different or pathogens occurred at the same time on one host The control ability of dually antagonistic bacteria to oppose disease complexes had been discovered (Son et al., 2009; Adam et al., 2014). Straight spreading biological control agents in the soil is the common method of application, but it led to less functional agents' activity.

Earlier some researchers reported a good result of biofertilizers made from a combination of biocontrol agents with some substrate such as straw from cereal crops, organic manure and compost (Dutta et al., 2015). When used as treatments, they manifested a good result to control soil borne disease hence the last one is considered as a new alternative way of biocontrol (Luo et al., 2010; Yang et al., 2011). This complexity of biofertilizers application is very effective to suppress soil borne disease than using one biocontrol agents (Liu et al., 2013). However, it must be applied when the functional of microbial strains is known and the amendments may be developed. The importance of biofertilizers is not only adding nutrients into the soil despite that they are a source of organic matter, improve soil structure, nutrient uptake increased due to less leaching which in turn boost plant growth (Shen et al., 2013). Furthermore, exudate antagonistic nutrients while allowing efficiency colonization increase suppressive capacity against pathogens (Zhang et al., 2011).

There are many bioagents that have been characterized to today (Ling et al., 2010), they are according to Son et al. (2009) and Asemoloye et al. (2019) commonly refers to as Plant Growth Promoting Rhizobacteria (PGPR) or Plant Growth Promoting Fungi (PGPF) and their application in soil for plant disease management have been widely encouraged by the soil scientists Fig. 4. The potentials of soil bioagents have recently been linked with the Systemic Acquired Resistance (SAR) as they have been proven to aid the plant resistance against some plant pathogens. Many bacteria and fungi have been characterized as bioagents, *Paenibacillus polymyxa* and *Paenibacillus lentimorbus* were affirmed to suppress root knot nematode and fusarium wilt fungus in infected plants by Son et al. (2009). In another study, Wang et al. (2010) affirmed the inhibitory and biocontrol effects of *Bacillus pumilus* strain AR03 against tobacco black shank disease. Asemoloye et al. (2017 a-c) reported the biostimulatory effects of some strains of rhizosphere fungi such as *Aspergillus niger*, *Yarrowia lipolytica*,

Talaromyces purpurogenus, *Talaromyces astroroseus*, *Trichoderma harzianum*, *Cunnighamella elegans* and so on. Many trichoderma strains are now available in commercial quantity as bioagents against plant diseases and biostimulants for the enhancement of plant growth.

CONCLUSION

Organic amendments and bioagents are natural alternatives that enhance organic farming and can be used in large scale to improve agriculture. These are natural enemies of pests and are likely to play an important role in plant disease control mechanisms in modern agriculture in the near future. There is need to develop effective strategies for using them massively in agriculture with more emphasis on research on development of pest control methods. The prices of the commercial biopesticides and bioagents are less competitive with synthetic chemical pesticides, alternately the government has to provide subsidies for encouraging their use in agriculture. Related regulations should go far enough in evaluating the broader impacts of organic amendments and bioagents and this will lead to an overall increased awareness and action about their benefits.

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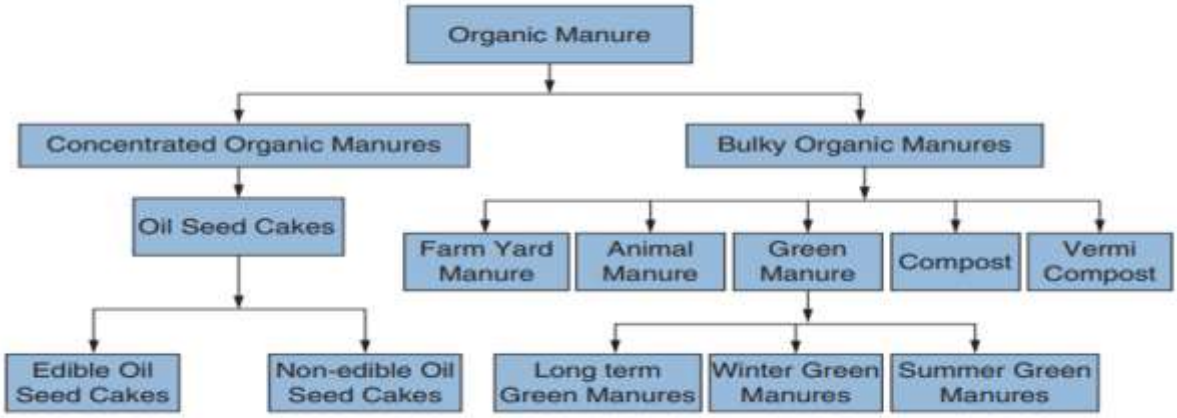

Fig. 1

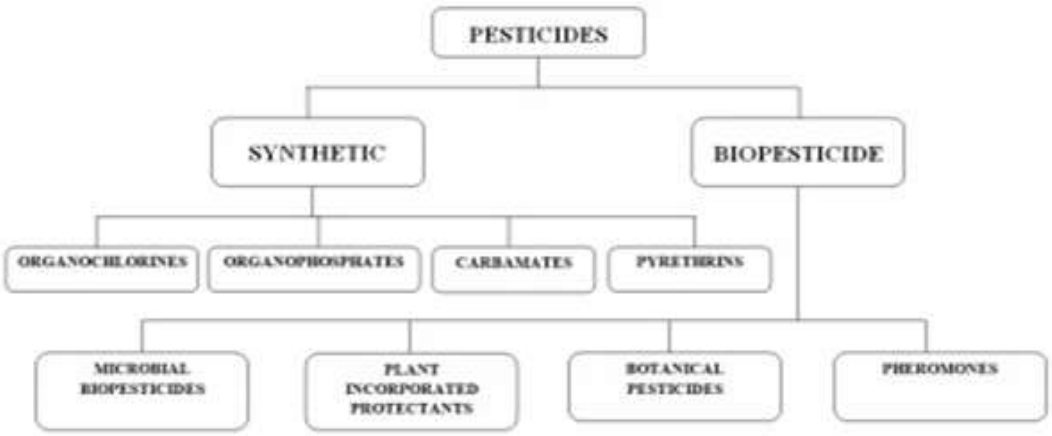

Fig 2

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Fig 3

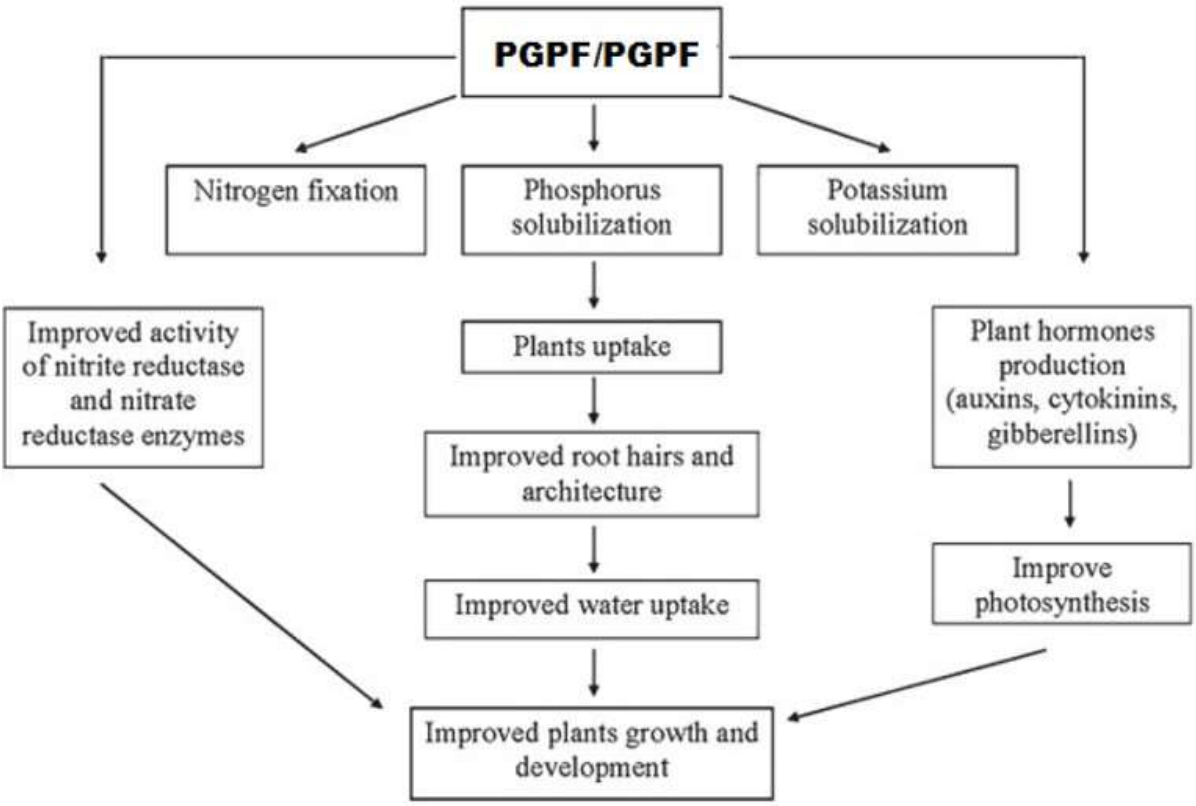

Fig 4

Abbreviations

DDT	Dichloro-diphenyl-trichoroethane
SIT	Sterile insect technique
AChE	acetylcholinesterase
PGPR	Plant Growth Promoting Rhizobacteria
PGPF	Plant Growth Promoting Fungi
SAR	Systemic Acquired Resistance
Ca	Calcium
N	Nitrogen
K	Potassium
P	Phosphorus
Mg	Magnesium
NH+4	Ammonium

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