The Concept and Theories of Effective Microorganisms

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Abstract
A principal goal of nature farming is to produce abundant and healthy crops without the use of chemical fertilizers and pesticides and without causing adverse effects on the natural environment. One means of achieving this goal is through the use of effective microorganisms (EM). The benefits of EM in increasing crop yields, improving crop quality, and protecting plants from pests and disease have been demonstrated for a wide range of crops and soil conditions. The concept of EM is based on the inoculation of mixed cultures of beneficial microorganisms into soil where they shift the microbiological equilibrium and create an environment that is favorable to the growth and health of plants. A series of inoculations are made to ensure that the introduced microorganisms continue their dominance over the indigenous populations. The exact mechanism of how EM acts and interacts in the soil-plant ecosystem is not known. However, there is evidence that supports a number of theories concerning the action of EM. These include the suppression of plant pathogens and diseases, conservation of energy in plants, solubilization of soil minerals, soil microbial-ecological balance, photosynthetic efficiency, and biological nitrogen fixation. Future research will help to verify these hypotheses.

Introduction

The health of plants is affected by numerous biotic and abiotic interactions in soil and at root surfaces. This relatively unexplored aspect of plant biology is of considerable interest today because of the opportunity to apply biotechnological advances in exploiting beneficial microorganisms for enhancing plant growth and protection. This awareness has created some unique opportunities for the entrepreneur.

In conventional agriculture, chemical fertilizers, pesticides, and plant growth regulators are usually applied to increase the yield and quality of crops. However, the frequent and excessive use of these chemicals has often resulted in adverse environmental effects, disturbing the ecological balance of soils, and making plants even more susceptible to posts and diseases. In some cases, crop yields and quality have actually declined. In attempting to deal with this situation, scientists have focused on the development of high yielding plant varieties that are more resistant to pests and diseases.

The public has become increasingly concerned about the possible health hazards of chemical residues in food and the environmental pollution that has resulted from their use. Scientists themselves are asking such questions as: What are the differences in chemical, physical and microbiological properties of soils treated with agricultural chemicals and untreated soils? Can we farm successfully without the use of chemical fertilizers and pesticides? What are the alternatives to chemical-intensive conventional farming?

It has long been known that regular additions of organic amendments to soil, including crop residues, animal manures, green manures, nightsoil, and composted organic wastes, can markedly improve soil productivity, fertility, and tilth. It is also known that such amendments can significantly increase the numbers of beneficial microorganisms in the soil. For many years scientists have investigated the beneficial effects of their activities such as biological nitrogen fixation, organic matter decomposition, mineralization, nitrification, antagonism (to soil borne plant pathogens), and fermentation.

Since 1980, Professor T. Higa has been exploring alternative methods for a more sustainable agriculture in his investigation of the unique characteristics of some beneficial microorganisms that he collectively calls effective microorganisms or EM. Professor Higa has promoted the term natural farming or nature farming which is not simply farming without chemical fertilizers and pesticides; but rather it is organic farming with the added dimension of exploiting beneficial microorganisms to enhance soil quality and soil health. According to Professor Higa (1988), soils that are treated with effective microorganisms become disease-suppressive soils, zymogenic soils, and synthetic soils. The development and application of EM has raised a number of questions and theories on the role of beneficial soil microorganisms in agriculture. This paper discusses the concept of EM and some of the theories of how EM may be affecting the soil and plant environment.

The Concept of Effective Microorganisms

From his study of beneficial microorganisms, Professor Higa concluded that the introduction of mixed cultures of microorganisms to soils and plants would likely be more effective, and for a longer period of time, than pure cultures. In due course, he developed three such mixed cultures of beneficial microorganisms that he found to be particularly effective. A mixed solution culture of photosynthetic bacteria, ray fungi, yeasts, and fungi, consisting of 10 genera and 80 different species he called EM 2. A mixed culture of photosynthetic bacteria is called EM 3. A mixed culture of Lactobacillus, and other microorganisms producing lactic acid, is called EM 4.

Experiments with the EM cultures have shown that both soil and foliar applications of EM can increase the yield and quality of various horticultural crops. For example, EM was found to significantly increase the content of vitamin C and sugar in fruit over that of the control. Today, EM is distributed under a registered trademark, and widely used on agricultural and horticultural crops in Japan including mango, tomato, spinach, brassica, allium, green pea, rice, cucumber, melon, and strawberry.

Theories of Effective Microorganisms

How can the application of EM to soil increase the yield and quality of crops? How does EM protect plants from pathogens and disease? Can disease-suppressive soils, zymogenic soils, and synthetic soils be induced by the application of EM? To answer these and other questions concerning the mechanisms of how EM acts and interacts in the soil-plant environment, it may be helpful to consider the following theories.

Disease-Suppressive Soil

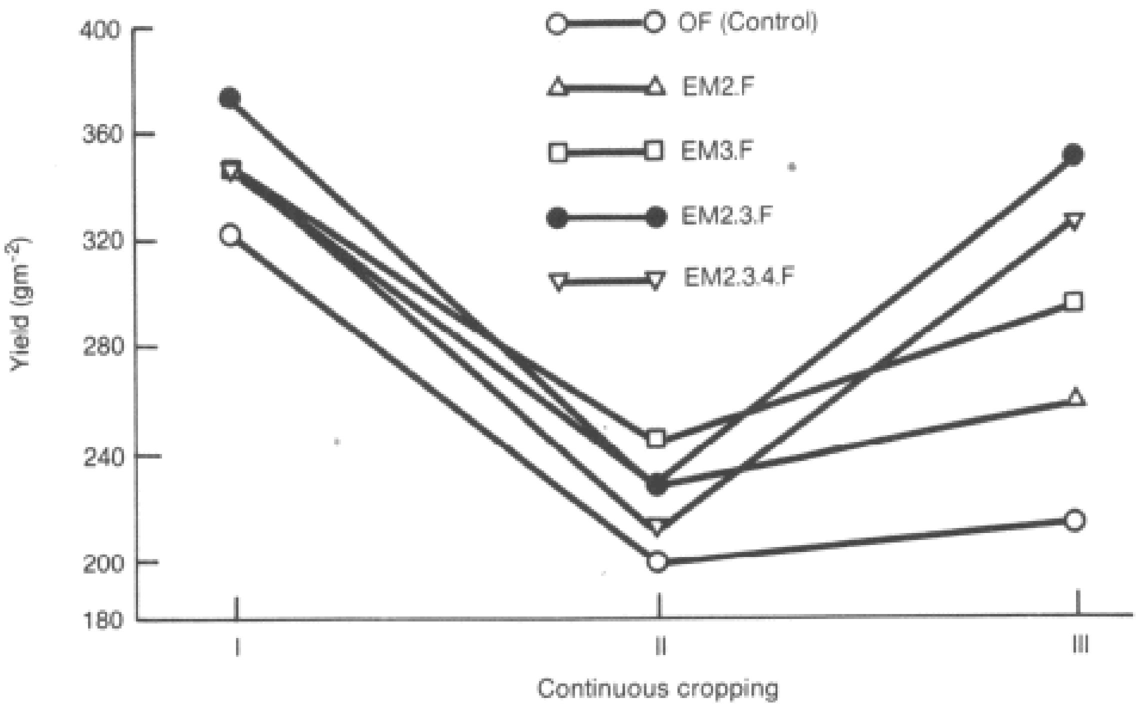
Theory The term disease-suppressive soil refers to the biological means of suppressing the occurrence of plant diseases. Three examples of disease-suppressive soil are: (1) the pathogen fails to become established, (2) the pathogen is present but fails to cause disease and (3) the pathogen causes disease but declines with monoculture.

Figure 1 shows that the application of EM cultures to soil increased the yield of green pea over that of a fertilized control for three successive crops. Figure 2 shows that EM treated soil increased significantly in total numbers of fungi which, in turn, suppressed the incidence of plant pathogenic *Fusarium*. Other experiments have shown that soil treated with EM 2. 3.4 had a lower incidence of plant fungal diseases (*Thielaviopsis* and *Verticillium*) and bacterial diseases (*Xanthomonas*, *Erwinia*, *Agrobacterium* and *Pseudomonas*) than the fertilized control. The suppression of plant pathogens and disease incidence is dependent on soil conditions, the plant, and which EM culture or combination of cultures is applied. This indicates that EM can induce a soil to become disease-suppressive in nature.

Organic Energy Theory

In the conventional theory, organic materials added to soil undergo decomposition by microorganisms, and minerals (nutrients) are released and become available for uptake by plants. In the organic energy theory, organic amendments are fermented by species of *lactobacillus*, and other lactic acid producing microorganisms. This, in turn, releases amino acids and saccharides as soluble organic compounds that are absorbed intact by plants to be utilized beneficially in various metabolic pathways. Kinjo (1990) found that the amount of amino acid produced after incubation of organic matter with EM for five days was significantly higher than the control without EM. The absorption of amino acids, sugars, and other organic compounds by plant roots has been demonstrated in plant tissue culture. Such work indicates that the plantlet, callus, or plant cell requires not only macro and micronutrients, but can also benefit from absorption of energy-yielding organic molecules such as amino acids and simple sugars.

The fermentation process is often utilized in the preparation of foods such as miso (soybean paste) and soy sauce, and in making silage for livestock. However, fermentation in soil and how it benefits the plant has been studied very little.



OF:	**Chemical Fertilizer (Control)**
EM 2.F:	**EM 2 and Chemical Fertilizer**
EM 3.F:	**EM 3 and Chemical Fertilizer**
EM 2.3.F:	**EM 2.3 and Chemical Fertilizer**
EM 2.3.4.F:	**EM 2.3.4 and Chemical Fertilizer**

Figure 1. Effect of EM and Chemical Fertilizer on Green Pea Production.

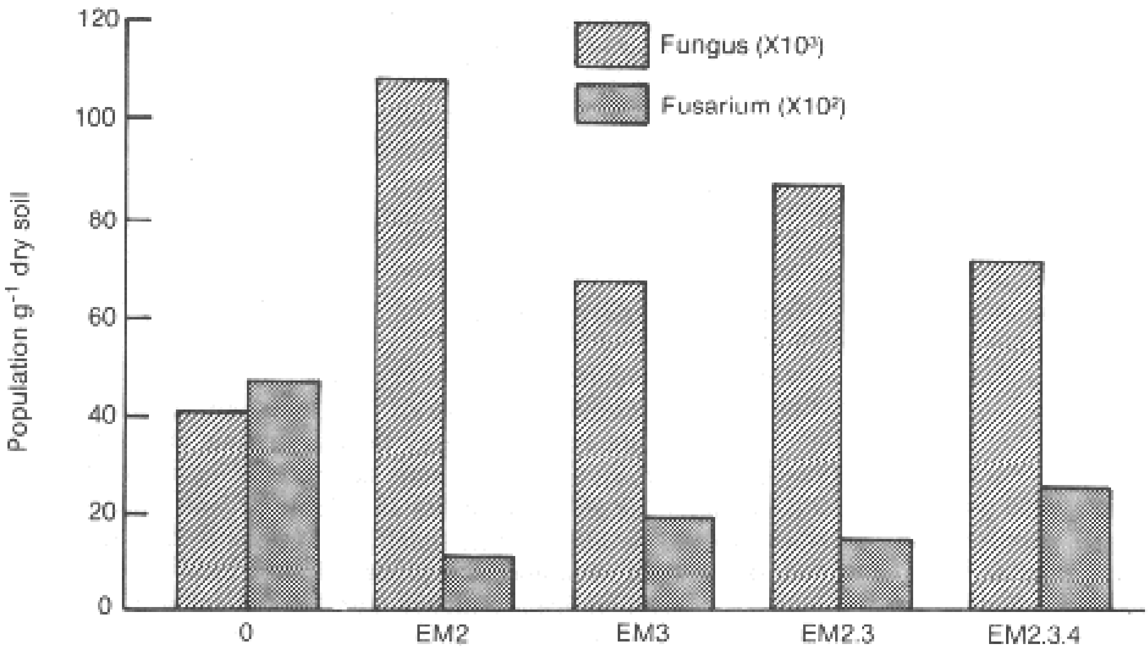


Figure 2. Effect of EM and Chemical Fertilizer on Soil Fungus and Fusarium population

Inorganic Nutrient Solubilizing Theory
Soil microorganisms are important in decomposing organic materials and recycling their nutrients for uptake by plants. Soil productivity generally decreases as soil organic matter decreases (often through soil erosion and insufficient return of organic wastes and residues to land). When this happens, the total soil microbial population and its biodiversity also tend to decrease.
Experiments were conducted in which a 0.1 % aqueous solution of molasses was applied to soil and to leaf surfaces of turnip (*Brassica rapa*) and green pepper (*Capsicum sp*.) as a carbon and energy source for indigenous microorganisms. The results showed a significant increase in the number of bacteria, actinomycetes, and fungi in both soil and on leaf surfaces over that of the unamended control (Tables 1 and 2). The foliar-applied molasses also Caused a substantial increase in the numbers of nitrogen fixing bacteria on the surface of turnip leaves (Table 2). The yield of both green pepper and turnip was significantly increased by the association of the increased number of microorganisms (Table 3).

Table 1. Effect of Molasses Spray Applied to Soil on Numbers of Microorganisms.

Microbial Group	Dilution	Number of Microorganisms*	
		Control	Molasses (0.1%)
Fungi	10^3	44.4	102
Fusarium	10^2	102	413
Bacteria	10^6	252	407
Actinomycetes	10^6	2.51	3.51

* Numbers per g of soil (dry weight basis). Microorganisms were counted in soil that was planted to green pepper.

Table 2. Effect of Foliar-Applied Molasses Spray on Numbers of Microorganisms on the Leaf Surface of Turnip.

Microbial Group	Dilution	Number of Microorganisms*	
		Control	Molasses (0.1%)
Fungi	10^2	12.4	63.3
Fusarium	10^2	8.42	14.0
Bacteria	10^4	3.89	8.90
Actinomycetes	10^4	2.46	9.21
N Fixing Bacteria	10^3	1.42	10.3

* Numbers per g of soil (dry weight basis). Microorganisms were counted on the leaf surface of Turnip.

Table 3. Effect of Foliar-Applied Molasses Spray on the Yield of Green Pepper and Turnip.

Treatment	Green Pepper *gm^{-2}*	Turnip *gm^{-2}*
Control	748	3660
Molasses (0.1 %)	964*	4140*

* Significant difference between treatments at 5% probability by Duncan's test.

Insoluble organic phosphorus compounds that are largely unavailable to plants can often be solubilized by microorganisms. Similar results were obtained in an experiment where various EM cultures were added to soil. As shown in Figure 3, there was a substantial increase in inorganic phosphorus (P_2O_5) due to EM compared with the unfertilized control.

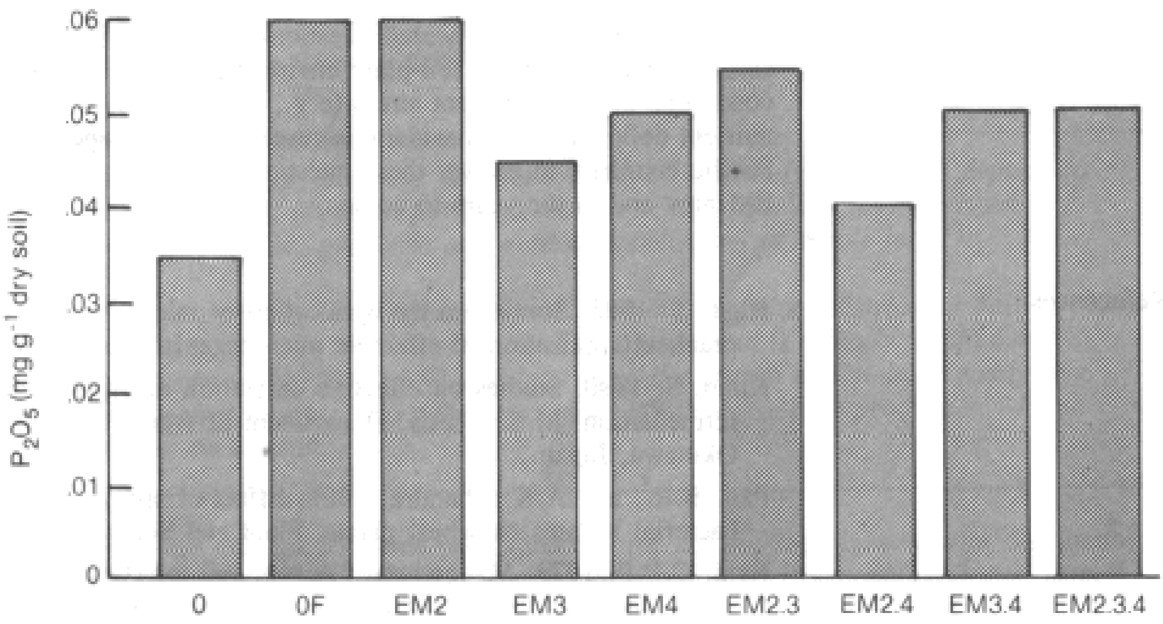


Figure 3. Effect of EM treatment on Soil P_2O_5 Content.

Balanced Population of Soil Microorganisms Theory

The incidence and severity of plant diseases depend on soil conditions, i.e., chemical, physical, and microbiological properties; soil management, i.e., tillage, fertilizers, and pesticides; crop management, i.e., crop rotation, monoculture, and multiple cropping; and the plant cultivar, i.e., disease-susceptible and disease-resistant. These factors can greatly influence the total microbial population, and its complexity and diversity, in soil. The balance in population and diversity between harmful and beneficial microorganisms will determine the soil microbiological equilibrium, and whether the soil ecosystem is favorable or unfavorable to the growth and health of plants. Generally, soils which have high populations of actinomycetes, *Trichoderma*, *Penicillium*, fluorescent pigment-producing *Psendomonas*, and other microorganisms that are antagonistic to plant pathogens, are considered to be disease-suppressive soils. Those which have large numbers of Lactobacillus and other fermentative microorganisms (yeasts, starch digesting bacteria, and cellulose digesting bacteria) are considered to be zymogenic soils. Soils which have large numbers of nitrogen fixing bacteria (*Azotobacter*, *Beljerinckia*, *Derxia*, and *Spirillum*), facultative anaerobic bacteria (*Bacillus*, *Enterobacter*, *Klebsiella*, and *Clostridium*), and photosynthetic bacteria are classified as synthetic soils. When a soil has high populations of plant pathogenic fungi (*Fusarium*, *Thielaviopsis*, *Phytophthora*, *Verticillium* and *Pythium*), it is considered to be a disease-inducing soil.

Photosynthetic and Nitrogen Fixing Theory

When EM are applied to soil or plant leaf surfaces, the populations of photosynthetic bacteria and nitrogen fixing bacteria increase dramatically. This phenomenon is associated with the growth of more vigorous plants, higher plant yields, and improved crop quality (based on higher contents of vitamin C and sugar in fruits) compared with no EM treatment. It was thought that the high number of photosynthetic bacteria and nitrogen fixing bacteria in soil and at leaf surfaces might enhance the plant's photosynthetic rate and efficiency, and its nitrogen fixing capacity. However, this has not been established experimentally. In this regard, Reid (1979) found that the net photosynthesis of *Pinus ponderosa* and *P. flexilis* tended to increase as the extent of infection by ectomycorrhizae increased.

Ruinen (1970) was among the first to investigate the occurrence of nitrogen fixing bacteria on leaf surfaces. Pati and Chandra (1981) and Sen Gupta et al. (1982a; 1982b) reported that nitrogen fixing bacteria on leaf surfaces could markedly increase crop yields.

Questions Concerning the Scientific Validity of Effective Microorganisms

There are those who doubt whether it is possible to introduce microorganisms into the soil-plant environment and actually shift the microbiological equilibrium in such a way as to derive beneficial effects on plant growth and yield. They say that this is possible only in the case of legume seed inoculation with *Rhizobium* species in which very large numbers of bacterial spores are placed on the seed coat to ensure survival and root infection, Moreover, most microbiologists are aware that early attempts to inoculate beneficial microorganisms into soils were made with single applications using pure cultures which consistently failed to elicit the hoped for beneficial response. The reason for this is that the introduced microorganisms would soon die out in a hostile or unfavorable soil environment.

Whether or not it is scientifically valid to inoculate a soil with a mixed culture of microorganisms, one needs only to consider such acceptable practices as adding animal manures, crop residues, and green manures to agricultural soils. All of these organic materials are colonized by populations of beneficial microorganisms that are not indigenous to soils but can, indeed, shift the soil microbiological equilibrium (at least temporarily) in ways that enhance crop yields and plant protection. A refined version of this is using EM to introduce mixed cultures of beneficial microorganisms into the agroecosystem, and to ensure their optimum effect through periodic and repeated applications.

Certainly there are unanswered questions concerning the actual mechanisms of how EM acts and interacts in the soil-plant environment, and the effectiveness of EM under conditions of soil and plant stress (e.g., severe drought, high soil temperatures, and soil nutrient deficiencies). Considerable research is now underway in a number of Asian and Pacific countries to answer these questions which should enhance the scientific validity of EM now and in the years to come.

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