Transition from Conventional Agriculture to Nature Farming Systems: The Role of Microbial Inoculants and Biofertilizers

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Introduction

The 1980 "USDA Report and Recommendations on Organic Farming" (USDA, 1980) documented the experiences of farmers who had shifted abruptly from conventional, chemical-based agriculture to organic or nature farming systems without chemical fertilizers and pesticides. Among the most frequently cited problems were:

- Increased weed and insect infestation.
- Plant nutrient deficiencies and imbalances.
- Reduced crop yields.

After the establishment of sound crop rotations, improved soil management practices, and renewed emphasis on timeliness and precision of farm operations, the farmers found that these problems could be dealt with effectively and that acceptable economic yields were possible. Farmers who participated in the USDA study reported that this often-difficult, high risk transition from conventional to organic/nature farming could take up to three years or more.

Today because of growing concerns about food safety and quality, potential impacts on wildlife, and pollution of surface water and groundwater, USDA is exploring new approaches and alternatives to help farmers reduce their dependence on agricultural chemicals, especially pesticides. The successful transition from conventional to organic/nature farming often requires an improvement in soil quality which can be achieved through the proper and regular addition of organic amendments to optimize soil tilth, fertility and productivity (Allison, 1973; Parr and Hornick, 1992a,b). Through natural processes and selection, these amendments also tend to increase the numbers and diversity of beneficial soil microorganisms which are vital to the growth, nutrition and protection of plants. This paper discusses strategies for reducing the time and risk of transition through the use of:

- Organic amendments and biofertilizers to improve soil quality and,
- Microbial inoculants, such as Effective Microorganisms (EM) to establish a new soil microbiological equilibrium that enhances soil health and is conducive to crop growth, yield and quality.

Soil Erosion and the Loss of Productivity

Today in the U.S., soil erosion by wind and water, the associated decline in soil productivity, and the adverse effects on water quality, continue to be our most serious agricultural and environmental problems (Larson et al., 1990). Much of this has been the result of improper and exploitive farming practices related to intensive cash grain production. The "soil erosion crisis" must be considered in a global context because the production, distribution, and consumption of food are part of the global economy. The mean annual loss of productivity may not easily be restored, even with application of chemical fertilizers. Studies have shown that when the topsoil is removed, or where it has been severely eroded, crop yields are from 20 to 65 percent lower compared with non-eroded soils (Langdale et al., 1979; Massee, 1990).

An important relationship often overlooked for most agricultural soils is that the degradative processes such as soil erosion, nutrient runoff losses, and organic matter depletion are occurring simultaneously with the beneficial effects of conservation practices such as crop rotations, conservation tillage, and recycling of animal manures and crop residues (Hornick and Parr, 1987). As soil degradative processes proceed and intensify, soil productivity decreases concomitantly. Conversely, soil conservation practices tend to slow these degradative processes and increase soil productivity. Thus, the potential productivity of a particular soil at any point in time is the result of ongoing degradative processes and applied conservation practices. Generally, the most serious degradative processes are soil erosion and associated depletion of plant nutrients and organic matter. On our best agricultural soils, i.e., gently sloping, medium-textured, well-structured, and with a deep, well-drained profile, a high level of productivity can be maintained by relatively few, but essential conservation practices that readily offset most degradative processes. However, on marginal soils of limited capability, i.e., steeply sloping, coarse-textured, poorly-structured soils depleted of nutrients, and with a shallow, poorly-drained profile, soil conservation practices must be maximized to counteract further degradation.

Thus, a truly sustainable farming system is one in which the beneficial effects of various conservation practices are equal to or exceed the adverse effects of degradative processes. Organic wastes and residues offer the best possible means of restoring the productivity of severely eroded agricultural soils or of reclaiming marginal soils (Parr and Hornick, 1992a,b).

The Concept of Sustainable Agriculture and Alternative Agriculture

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to over-come problems and constraints which confront the economic viability, environmental soundness, and social acceptance of agricultural production systems both in the U.S, and worldwide (Reganold et al., 1990). While there are many definitions of sustainable agriculture, most of them encompass the same elements of productivity, profitability, conservation, health, safety and the environment, differing only in the degree of emphasis. Furthermore, "sustainable" implies a time dimension and the capacity of a farming system to evolve and endure indefinitely (Parr et al., 1992).

The Agricultural Research Service (USDA) defines sustainable agriculture as: Agriculture that for the foreseeable future will be productive, competitive and profitable, conserve natural resources, protect the environment, and enhance public health, food quality, and safety.

In 1989, the National Research Council concluded that the ultimate goal of sustainable agriculture is to develop farming systems that are productive and profitable, conserve the natural resource base, protect the environment, and enhance health and safety (all of this over the long-term) (NRC, 1989).

Alternative agricultural practices provide the best means of achieving this goal. The National Research Council defined alternative agriculture as a system of food and fiber production that applies management skills and information to reduce input costs, improve efficiency, and maintain production levels through such practices and principles as:

- Crop rotations in lieu of mono culture.
- Integrated crop/livestock systems.
- Nitrogen-fixing legumes.
- Integrated pest management.
- Conservation tillage.
- Integrated nutrient management.
- Recycling of on-farm wastes as soil conditioners and biofertilizers.

It is also important to note that the single most important component of a sustainable farming system is skilled management.

Alternative agriculture seeks to optimize the use of internal production inputs (i.e., on-farm resources) and skilled management in ways that provide acceptable levels of sustainable crop yields and livestock production, and result in economically-profitable net returns. This approach emphasizes such cultural and management practices as crop rotations, use of animal and green manures, and conservation tillage to control soil erosion and nutrient losses.

In the United States, achieving a more sustainable agriculture has become the ultimate goal. How we achieve this goal will depend on creative and innovative conservation and production practices that provide farmers with economically-viable and environmentally-sound alternatives or options in their farming systems. While low-input/sustainable farming systems may be feasible in developed countries, it is likely that inputs in many developing countries will have to be increased substantially to raise the production potential above a subsistence level before agricultural sustainability can be achieved (Parr et al., 1994). From this discussion, it is readily apparent that alternative agricultural practices and the ultimate goal of a long-term sustainable agriculture depend largely, and vitally, upon regular additions of various organic amendments to soils.

The Concept of Soil Quality

Various physical, chemical, and biological properties of soils interact in complex ways to determine their potential fitness or capability for sustained production of healthy, nutritious crops. The integration of growth-enhancing factors that make a soil productive has often been referred to as "soil quality". Thus, soil quality has traditionally focused on, and has been equated with, soil productivity. More recently, the concept of soil quality has been broadened to include attributes of food safety and quality, human and animal health, and environmental quality (Parr et al., 1992). In view of this, soil quality might then be defined as:

> The capacity or capability of a soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or adversely affecting the environment.

Although not well understood, soil quality may also play a major role in plant health and in the nutritional quality of the food that is produced. Thus, if properly characterized, soil quality should serve as a measure or indicator of changes in (a) the soil's capacity to produce optimum levels of safe and nutritious food, and (b) it's structural and biological integrity which can relate to the status of certain degradative processes, as well as environmental and biological plant stresses.

Soil quality can decline through various degradative processes. Thus, soil quality is directly related to soil degradation which also can be defined as the time/rate of change in soil quality (Parr et al., 1992). The maintenance or restoration of soil quality is highly dependent on organic matter and an array of beneficial macro- and microorganisms that it supports. The proper and regular addition of organic amendments such as animal manures and crop residues can effectively offset many of these degradative processes (Hornick and Parr, 1987). It is also the best and most expedient means of developing a biologically-active soil that requires less energy for producing crops; increases the resistance of plants to pests and diseases; and enhances the decomposition of toxic substances such as residual pesticides.

Soil Quality: The Linkage between Alternative Agriculture and Sustainable Agriculture

It was mentioned earlier that soil quality is now considered by many in a broader context than just soil productivity; i.e., that the concept should include the attributes of food safety and quality, human and animal health, and environmental quality. It follows then, that the best means of improving and maintaining soil quality are alternative agricultural practices such as crop rotations, recycling of crop residues and animal manures, reduced input of chemical fertilizers and pesticides, and increased use of cover crops and green manure crops, including nitrogen-fixing legumes. All of these help to maintain a high level of soil organic matter that enhances soil tilth, fertility, and productivity, while protecting the soil from erosion and nutrient runoff. Effective implementation of these alternative agricultural practices using a holistic or systems approach requires skilled management and innovativeness by the farmer.

The attributes of soil quality provide a vital link between the strategy of alternative agriculture and the ultimate goal of sustainable agriculture. Soil quality occupies a pivotal position in this concept. Indeed, many would agree that soil quality is the "key" to agricultural sustainability (Pam et al., 1992).

The Value of Organic Wastes as Biofertilizers and Soil Conditioners

The simplest and most common method of estimating the value of organic wastes is to consider them as substitutes for chemical fertilizers. This is done by assessing the current market value of their plant nutrient content, usually limited to the macro nutrients N, P, and K, while excluding all others. One can make a strong argument that the organic component of these wastes for improving

soil tilth and productivity can be a substantial benefit. Unfortunately, the benefits of the organic component are often not considered (Parr and Colacicco, 1987).
In addition to the fertilizer value of organic wastes, it is often important to distinguish between their agronomic and economic values. Among the other "values" of organic wastes are the animal feed value; the water gain value; the soil conservation value; and the soil-carbon sequestration value. All of these attributes of organic wastes and residues can be quantified and evaluated (Parr et al., 1994).
The important consideration is that good quality organic wastes and residues, composted or otherwise, that are utilized as biofertilizers and soil conditioners have a far greater value than just their macro nutrient content. These materials have a much greater residual effect on soil tilth and fertility than most chemical fertilizers because of the slow-release character of their nitrogen and phosphorus components. Thus, a significant portion of the economic value of organic wastes is their capacity to elicit crop yield responses over time. This response must be accounted for to assess the true value of the material. The cumulative agronomic and economic value of some organic materials applied to agricultural soils could be more than five times greater in the post-application period than the value realized during the initial year of application (Barbarika et al., 1980).

Use of Microbial Inoculants to Optimize Crop Production and Protection

Controlling the Soil Microflora

The idea of controlling and manipulating the soil microflora through the use of microbial inoculants, organic amendments, and cultural management practices, to create a more favorable soil microbiological environment for optimum crop production and protection is not new. For at least five decades, microbiologists have known that organic wastes and residues, including animal manures, crop residues, green manures, municipal wastes (both raw and composted) contain their own indigenous populations of microorganisms, often with broad physiological capabilities. It is also known that when such organic wastes and residues are applied to soils many of these introduced microorganisms, can function as biocontrol agents by controlling or suppressing soil-borne plant pathogens through their competitive and antagonistic activities. While this has been the theoretical basis for controlling the soil microflora, in actual practice the results have been unpredictable and inconsistent, and the role of specific microorganisms has not been well-defined (Papavizas and Lumsden, 1980).

Possible Mechanisms Induced by Microbial Inoculants

There have been many reports on the possible mechanisms that can shift the soil microbiological equilibrium following the addition of microbial inoculants and organic amendments. A brief mention of these is relevant to the subject.

- Antibiosis - production of antibiotics by non-pathogenic microorganisms that can induce biostasis and biocidal effects on others.
- Competition - competition by microorganisms for substrates, space and growth factors.
- Parasitism - direct parasitic attack on soil-borne plant pathogens by non-pathogenic microorganisms.
- Detoxification - metabolism of toxic substances by specific microorganisms.
- Inhibition - production of compounds by microorganisms that can inhibit specific metabolic pathways in others.

Pure Cultures or Mixed Cultures?

For many years microbiologists have tried to culture beneficial microorganisms for use as soil inoculants to overcome the harmful effects of phytopathogenic organisms, including bacteria, fungi, and nematodes. Such attempts have often involved single applications of pure cultures of microorganisms which have been largely unsuccessful for several reasons. First, we did not thoroughly understand the individual growth and survival characteristics of each particular beneficial microorganism, including their nutritional and environmental requirements. Second, our knowledge of their ecological relationships and interactions with other microorganisms was lacking. And third, the pure culture inoculant was often not at a sufficiently high inoculum density to

enhance the probability of its growth, survival and adaptation in a soil environment (Higa, 1994).
When various organic amendments containing mixed cultures of indigenous microorganisms are applied as soil amendments and biofertilizers, some species tend to survive longer than others. However, most of them tend to "die away" following the peak of growth and activity resulting from utilization and depletion of available substrate carbon by the soil microflora. In effect, the inoculated microorganisms are overwhelmed by the native soil microflora through competition and antagonism.

What We Need to Know About Microbial Inoculants

The use of microbial inoculants to improve soil quality and health, to enhance crop yield and quality, and to reduce our dependence on agrichemicals is a promising new technology with great potential. However, we need to know more about their mode of action and interaction in the soil-plant ecosystem. Therefore, the following research should be given a high priority to optimize the effectiveness of microbial inoculants in agriculture:

- Ensure a high level of consistency in performance and benefits.
- Determine the effects of pure culture and mixed culture inocula.
- Determine the modes of action of inocula on the indigenous soil microflora and on plant growth, yield, quality and protection.
- Ensure quality control for producing inocula with respect to inoculum density and activity.
- Determine the practicability and feasibility of using microbial inoculants to enhance and improve the species and genetic diversity of marginal soils.
- Determine and monitor the survival and dispersal of inocula in treated soils.

The Concept of Effective Microorganisms

A unique approach for controlling the soil microflora and for maximizing their beneficial effects is that which has been developed by Professor Teruo Higa at the University of the Ryukyus in Okinawa, Japan. Professor Higa is the innovator of the concept of Effective Microorganisms or EM which has emerged as a promising new technology. EM consists of mixed cultures of naturally-occurring, beneficial microorganisms that can be applied as inoculants to increase the microbial diversity of soils and plants. Research has shown that as these EM cultures become established they can improve soil health and quality, and the growth yield and quality of crops (Higa and Wididana, 1991; Higa, 1994; Higa and Parr, 1994; Higa, 1996).
The exact mechanisms of how EM interacts and functions in the soil-plant ecosystem is not known. However, there is evidence that supports several theories concerning it’s action including a) suppression of plant pathogens and diseases, b) enhanced nutrient availability, c) stimulated plant growth (i.e., auxin-mediated effects), and d) improved root surface-rhizosphere relationships (Higa and Wididana, 1991).
EM cultures are particularly effective in promoting plant growth and protection during the first three to four weeks after planting. This is the period when seedlings are so vulnerable to stress factors such as drought, heat, weeds, insects and diseases. It is also the time when the greatest loss in crop yield and quality can occur. Reports indicate that EM-treated plants are able to resist these stress factors more readily (Higa and Pam, 1994).

Summary and Conclusions

1. Successful transition from chemical-based, conventional agriculture to nature farming systems requires skilled management of a holistic system and timeliness and precision in farm operations.
2. Proper and regular additions of organic amendments are vital for maintaining and improving soil quality.
3. Soil quality is the "key" to a more sustainable agriculture.

4. Linkages between soil quality, soil health, crop quality, food quality and human health and nutrition need to be identified and verified.
5. Microbial inoculants of beneficial microorganisms control the soil microbiological equilibrium in ways that can improve soil quality and health, and enhance the growth, yield and quality of crops.
6. Organic amendments can help to ensure a high level of soil microbial diversity (i.e., types, numbers, and genetics).
7. Use of beneficial and effective microorganisms as microbial inoculants in agriculture is a promising new technology. Research is needed to determine their modes of action in the soil-plant ecosystem.

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