USE OF MICROBIAL INOCULANTS AND ORGANIC FERTILIZERS IN AGRICULTURAL PRODUCTION

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ABSTRACT

Because of exploitive and improper farming practices, agricultural lands worldwide have been subjected to such degradative processes as soil erosion by wind and water, nutrient depletion, and loss of soil organic matter, all of which have contributed to a serious decline in soil productivity. These degraded soils could be restored and rehabilitated vo an optimum level of productivity by proper and regular additions of various organic wastes including crop residues, animal manure, green manure, sewage sludge and municipal solid waste. Alternative agricultural practices and the ultimate goal of a long-term sustainable agriculture depend largely upon the addition of organic amendments to soil. However, the chemical and physical properties of these wastes may limit their acceptance by farmers as organic amendments. This paper discusses how composting and co-composting technologies can transform organic wastes into products that can be used safely and beneficially as soil conditioners and biofertilizers, and how the agronomic and economic value of these wastes can be estimated and quantified. Finally, the paper considers the potential use of microbial inoculants for controlling the soil microflora and achieving a more favorable environment for optimum crop production and protection.

INTRODUCTION

Soon after World War II, during the late 1940s and early 1950s, many farms in the United States began to shift from mixed crop-livestock operations to highly specialized, monoculture-type, cash grain production systems. This occurred because grain prices were high, energy costs were low, high-yielding varieties were available, credit was easily obtained, and the risk was low because of government subsidies and support programs. Livestock virtually disappeared from these systems and were confined to feedlots. Without crop rotations and animal manures to maintain soil productivity, farmers had to increase their inputs of chemical fertilizers and pesticides. Intensive tillage and the lack of appropriate conservation practices often resulted in excessive soil erosion and a decline in soil productivity.

Other problems associated with this type of agriculture were the pollution of surface and ground water by agrichemicals. Consequently, there has been a growing public concern about adverse impacts of agriculture on the environment and on the safety and quality of food. Questions have also been raised as to whether the agricultural production system of the United States is sustainable over the long term. In some developed countries, including the United States, there have been recent government initiatives to reduce the use of pesticides in food crop production. Such actions should foster renewed interest in crop rotations and organic recycling to enhance soil productivity, and the biological control of insect pests, plant diseases and soilborne pathogens. This has also stimulated current thinking on the possible use of microbial inoculants in shifting the soil microbiological equilibrium in ways that are favorable to the production and protection of crops.

Proper and regular additions of on-farm organic wastes such as animal manures and crop residues are of utmost importance in maintaining the tilth, fertility and productivity of agricultural soils;

Keywords: composting, microbial inoculants, organic fertilizers, soil microorganisms, sustainable agriculture,

protecting them from wind and water erosion; and preventing nutrient losses through runoff and leaching. Table 1 shows that these materials usually have predictable beneficial effects on a broad spectrum of soil properties (Allison 1973). Also, we should note that there is a growing shortage of good-quality on-farm organic wastes for use as soil conditioners and biofertilizers because of competitive uses as fuel, fodder and fiber (USDA 1978).

Because of intensive cash grain production practices, agricultural lands worldwide have become vulnerable to degradative processes such as soil erosion from wind and water, nutrient depletion and loss of organic matter, and have suffered a consequent decline in soil productivity. The restoration and rehabilitation of these degraded soils to an acceptable level of productivity can be enhanced by using various off-farm sources of organic wastes, including sewage sludge, municipal solid wastes, and agricultural and industrial processing wastes (USDA 1978; Hornick and Parr 1987; Parr and Hornick 1992a,b). However, the quality and acceptability of these materials as soil amendments can be greatly improved through composting, or even by co-composting them with available on-farm wastes.

This Bulletin discusses the dynamics of soil productivity; concepts of soil quality and sustainable agriculture as they relate to organic recycling; some guidelines on the composting of agricultural and municipal wastes for safe and beneficial use as soil conditioners and biofertilizers; some perspectives on the use of microbial inoculants; and the ways in which soil-applied organic amendments can be more realistically evaluated.

Table 1. Beneficial effects of organic amendments on soil properties.

Soil property affected	Beneficial effect
Nutritional	
Micronutrients	Cu, Mn, Zn, B, Cl, Mo
Macronutrients	O, H, C, N, P, S, Fe, Ca, Mg
Chemical	
Cation exchange capacity	Increases
Buffering capacity	Increases
Chelating capacity	Increases
pH	Alleviates acidic and alkaline conditions
Physical	
Soil aggregation	Increases
Aggregate stability	Increases
Water holding capacity	Increases
Soil porosity	Increases
Water infiltration	Increases
Water percolation	Increases
Soil crusting	Decreases
Bulk density	Decreases
Bioiogical	
Beneficial microorganisms	Produces polysaccharides/antibiotics Increases nutrient availability Suppresses plant pathogens Decomposes organic wastes
Earthworms	Populations increase

1 Throughout this paper we use the term "organic amendment" in reference to a wide array of organic materials, wastes, and residues of either rural or urban origin that when added to soils can improve their properties and crop yields, and impart such beneficial effects over time that will improve soil productivity (USDA 1957).

Source: Allison 1973

HISTORICAL PERSPECTIVE

Farming began to develop in the Far East and on the Asian mainland of China some time between 4000 and 3000 B.C. (Parr and Hornick 1992b). In the early 1900's, Dr. F.H. King, Chief of the Division of Soil Management, U.S. Department of Agriculture, became concerned about the exploitive farming practices in the United States and the concomitant soil degradation resulting from excessive erosion and loss of productivity. He questioned the sustainability of farming practices and whether we could maintain and conserve the fertility and productivity of our agricultural soils for future generations. He was curious how farmers in Asia had been able to sustain the fertility and productivity of their soils in view of such high population densities. During much of 1911, he traveled extensively in China, Korea, and Japan. Upon his return to the United States he wrote a book about his experience entitled "*Farmers of Forty Centuries: Permanent Agriculture in China, Korea, and Japan*" (King 1911). In King's own words:

> "We desired to learn how it is possible after twenty and perhaps thirty or even forty centuries, for their soils to be made to produce sufficiently for the maintenance of such dense populations as are living now in these three countries."

King found that the key to maintaining permanent and sustainable agriculture through the centuries in China, Korea and Japan was the regular and extensive recycling of a vast array of organic materials as soil conditioners and biofertilizers. Such materials included animal manures, green manures, nightsoil, crop residues, canal mud, wood ashes, tree leaves, aquatic weeds from canals, wild grasses, urban sewage and street refuse. Many of these materials were composted to destroy weed seeds and potential human and plant pathogens, to enhance their nutrient availability, to suppress malodors, and to facilitate storage, transport, and application to land. Organic recycling practices such as this allowed farmers to maximize their crop production with negligible soil erosion and nutrient runoff.

Agriculture in Asia has changed considerably in the 80 or more years since King's visit. Farming practices now focus more on intensive food and cash grain production and less on crop rotations. This requires heavy and frequent applications of chemical fertilizers and pesticides.

Farmers in Asia, as in the United States, must give a higher priority to short-term economic gain rather than long-term conservation and sustainability, in order to survive. Moreover, in view of the expanding populations of many Asian countries, and because all good arable land is now in use, an increasing number of subsistence-level farmers in the Asian-Pacific region must produce crops on marginal lands that are subject to rapid and irreparable degradation. Consequently, the countries that King visited have now become very concerned about soil erosion, nutrient runoff losses, loss of soil productivity, pollution of surface and groundwater by agricultural chemicals, and food safety and quality.

SOIL EROSION AND THE LOSS OF PRODUCTIVITY

Today in the United States, soil erosion by wind and water, and 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. Brown and Wolf (1984) concluded that the soil erosion crisis must be considered in a global context, because the production, distribution, and consumption of food is part of the global economy. They estimated that the mean annual loss of topsoil worldwide is about 0.7%. This is of great concern, because the loss of productivity may not easily be restored, even with the 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% lower compared with non-eroded soils (Langdale *et al.* 1979; Massee 1990).

Fig. 1 illustrates an important relationship that is often overlooked. For most agricultural soils, degradative processes such as soil erosion, nutrient runoff losses, and organic matter depletion are going on 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 the best agricultural soil in the United

States, that is, gently sloping, medium-textured, well-structured soils 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, such as 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 (Hornick and Parr 1987; Parr and Hornick 1992a,b).

THE CONCEPTS OF SUSTAINABLE AGRICULTURE AND ALTERNATIVE AGRICULTURE

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints that confront the economic viability, environmental soundness, and social acceptance of agricultural production systems both in the United States and worldwide. 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 (Lockeretz 1988).

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."

The U.S. Congress (1990) in drafting the 1990 Farm Bill defined sustainable agriculture as:

"An integrated system of plant and animal production practices having site-specific application that will, over the long-term:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource base
- Make efficient use of nonrenewable resources
- Utilize natural biological cycles and controls
- Improve the economic viability of farming systems
- Enhance the quality of life for farmers and society as a whole."

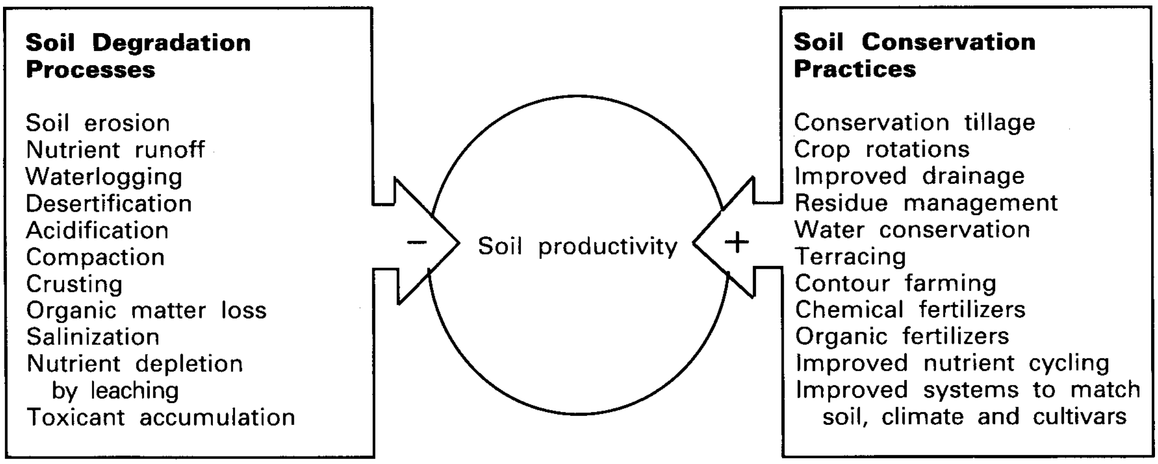

Fig. 1. Relationship of soil degradative processes and soil conservation practices.

Source: Hornick and Parr 1987

The National Research Council (NRC 1989) 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). 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 rotation in lieu of monoculture
- 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 (Parr *et al.* 1990; Reganold *et al.* 1990). 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. 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". The Soil Science Society of America (SSSA 1984) defines soil quality as an inherent attribute of a soil which is inferred from soil characteristics or indirect observations (e.g., compactability, erodibility, and fertility). 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 soil quality is not well understood, it 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) its 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 all of the degradative processes that are illustrated in Fig. 1. Thus, soil quality is directly related to soil degradation, which can also 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 the diversity of beneficial macro-organisms 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. 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 (Sampson 1981; Hornick and Parr 1987; Parr *et al.* 1992).

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., the concept includes 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 (Papendick and Parr 1989; Parr *et al.* 1983; Parr *et al.* 1989).

According to Parr *et al.* (1992), the attributes of soil quality provide a vital link between the strategy of alternative agriculture and the ultimate goal of sustainable agriculture (Fig. 2). Soil quality occupies a pivotal position in this concept. Indeed, many would agree that soil quality is the "key" to agricultural sustainability.

COMPOSTING TO IMPROVE THE QUALITY AND UTILIZATION OF ORGANIC WASTES

Composting is a viable means of transforming various organic wastes into products that can be used safely and beneficially as biofertilizers and soil conditioners. A number of the problems associated with the use of raw and unstable organic wastes as soil amendments can be resolved through composting, such as malodors, human pathogens, and undesirable chemical and physical properties. During the composting process, organic wastes are decomposed, plant nutrients are mineralized into plant-available forms, pathogens are destroyed, and malodors are abated (Parr and Hornick 1992a).

Composting is a practice that farmers have used for centuries to convert organic wastes into useful biofertilizers and soil amendments. More specifically, composting is a microbiological process that depends on the growth and activity of mixed populations of bacteria, actinomycetes, and fungi that are indigenous to the wastes being composted. Composting can be conducted by either aerobic or anaerobic methods. However, the aerobic mode is generally preferred, since it proceeds more rapidly and provides greater pathogen reduction because higher temperatures are attained. An example of an aerobic composting method is that developed by USDA scientists at the Beltsville Agricultural Research Center in Maryland, USA. The method is widely referred to as the Beltsville Aerated Pile Method, and utilizes a static pile with forced aeration to maintain aerobic, thermophilic conditions (Willson *et al.* 1980).

According to Parr *et al.* (1978), this particular mode of composting is defined as:

"The aerobic, thermophilic decomposition of organic wastes by mixed populations of indigenous microorganisms under controlled conditions which yields a partially stabilized residual organic material that decomposes only slowly when conditions again became favorable for microbiological activity."

Some organic wastes may have chemical, physical, and/or microbiological properties that would greatly limit the extent to which they could be composted alone. Some wastes may have an extremely acidic or alkaline pH, others may have an unusually high or low C:N ratio, and still others may vary widely in their solids content. In such cases, selective co-composting of these wastes with sewage sludge, pit latrine waste or night soil, municipal solid waste (i.e., garbage or refuse), crop residues, animal manures, food processing wastes and certain industrial wastes, may alleviate these deficiencies and provide a readily compostable mixture and higher quality product.

For example, rice straw has a very high C:N ratio and is slow to compost on its own. If it is combined with a low C:N material such as poultry manure, a more favorable ratio is achieved for rapid composting, and a compost is produced that has a higher nutrient content (Parr and Colacicco 1987; Willson 1989; Rynk 1992).

FACTORS AFFECTING THE COMPOSTING PROCESS

There are a number of factors which affect the composting process and which must be within an optimum range if aerobic, thermophilic composting is to proceed rapidly and effectively (Parr and Willson 1980, Willson 1989). These are summarized as follows:

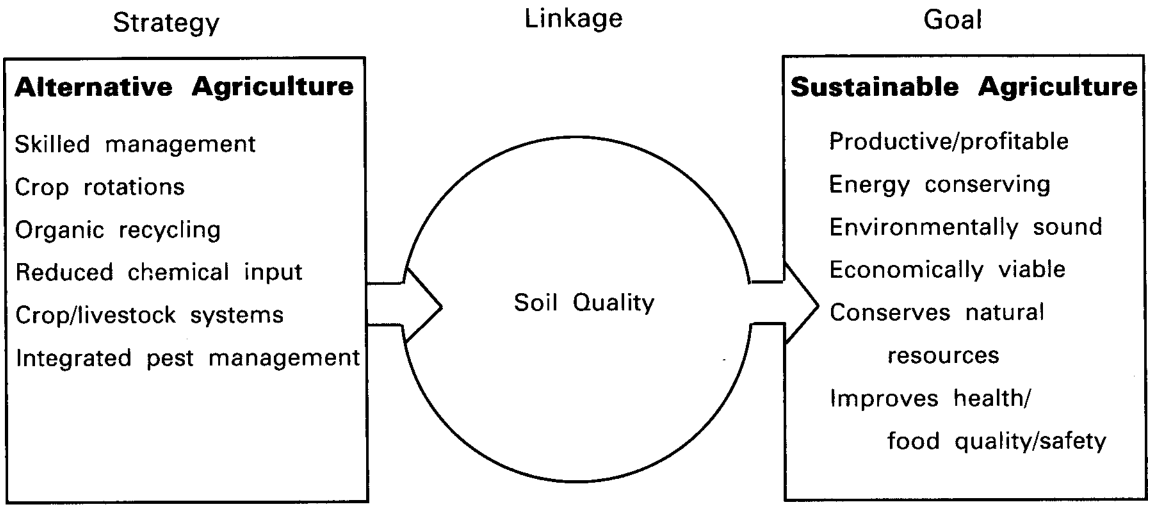

Fig. 2. A conceptual diagram that illustrates how the attributes of soil quality provide a link between the strategy of alternative agriculture and the ultimate goal of sustainable agriculture.

Carbon:Nitrogen Ratio

During composting, microorganisms require carbon for growth and energy, and nitrogen for protein synthesis. Thus, the rate of decomposition of organic wastes depends on a proper balance of carbon and nitrogen. Rapid composting is achieved when wastes or mixtures of wastes have a C:N ratio of between 15 and 35. Lower ratios can result in the loss of ammonia (NH_3), while higher ratios can slow the rate of composting.

Moisture Content

The optimum moisture content of organic wastes or mixtures of wastes for rapid aerobic, thermophilic composting ranges from 40 to 60% (by weight). If the moisture content is below 40%, decomposition will be aerobic but slow. If it is above 60%, there may be insufficient air space (because of excess moisture) to sustain aerobic decomposition, and anaerobic conditions may prevail.

Temperature

As composting proceeds, and if other factors are favorable, microbial activity causes temperatures to increase from the mesophilic range (20-40°) into the thermophilic range (>40°C). Optimum temperatures for rapid aerobic composting range from 55 to 65°C.

pH

Research has shown that the optimum pH for rapid composting of various wastes or mixtures of wastes ranges from 5.0 to 9.0.

Aeration/Oxygen Supply

A continuous supply of oxygen is required to ensure rapid aerobic, thermophilic composting. A rule-of-thumb is that the composting biomass must contain at least 30% free air space (i.e., total porosity).

Particle Size/Texture

Grinding, shredding and blending organic wastes can enhance the rate of decomposition during composting by providing a more favorable surface to volume ratio. However, excessive grinding can lead to compaction, loss of porosity, and anaerobic conditions.

If all of these factors are optimal, composting proceeds as indigenous microorganisms start to utilize the organic materials for available carbon, nitrogen, and other nutrients. As the activity continues, the temperature begins to increase from heat that is generated through microbial oxidations and respiratory functions. A typical time-temperature relationship for composting organic wastes under aerobic, thermophilic conditions is shown in Fig. 3 (Curve 1). If any of these factors are not at or near their optimum levels, then incomplete composting is likely to result (Curve 2).

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 macronutrients N, P, and K, while excluding all others. Table 2 shows the value of four common organic wastes (i.e., cattle manure, crop residues, sewage sludge, and municipal solid waste) based on their average macronutrient content (Parr and Hornick 1992a). This shows that cattle manure is worth $23.47/mt, while sewage sludge is valued at $21.40/mt. Crop residues and municipal solid waste both have a comparatively lower nutrient content, and thus a lower market value as fertilizer substitutes. 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.

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. These are discussed briefly as follows:

Fertilizer Value

This is estimated by assessing the current market value of the plant nutrients they contain. It does not consider the beneficial effects of the organic component.

Agronomic Value

This is based on the increased crop yield or quality derived from organic wastes applied to land. The highest agronomic value per unit of organic waste is usually obtained with the first few increments applied.

Economic Value

This represents the value of the increase in crop yield and crop quality that is derived from organic wastes applied to land. The highest economic value per unit of waste is usually obtained with the first few increments applied.

Animal Feed Value

Animal feed value is the value of the meat, milk, wool etc. that is produced from the consumption of crop residues by ruminant animals.

Water Gain Value

This is the net water conserved from crop residues and other organic materials managed as surface mulches, expressed as the value of increased yield of grain and straw per mm of water stored.

Soil Conservation Value

This represents the amount (value) of topsoil conserved when crop residues and other organic materials are managed as surface mulches compared with that lost from bare soil by wind and water erosion.

Soil-Carbon Sequestration Value

This is the net gain in soil carbon from the application of various organic wastes to soil, depending on the mode/method, time, rate and frequency of application. The objective is to maximize the fixation of soil carbon and minimize the loss of carbon dioxide to the atmosphere, where it would contribute to global warming.

The important consideration here 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 macronutrient 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

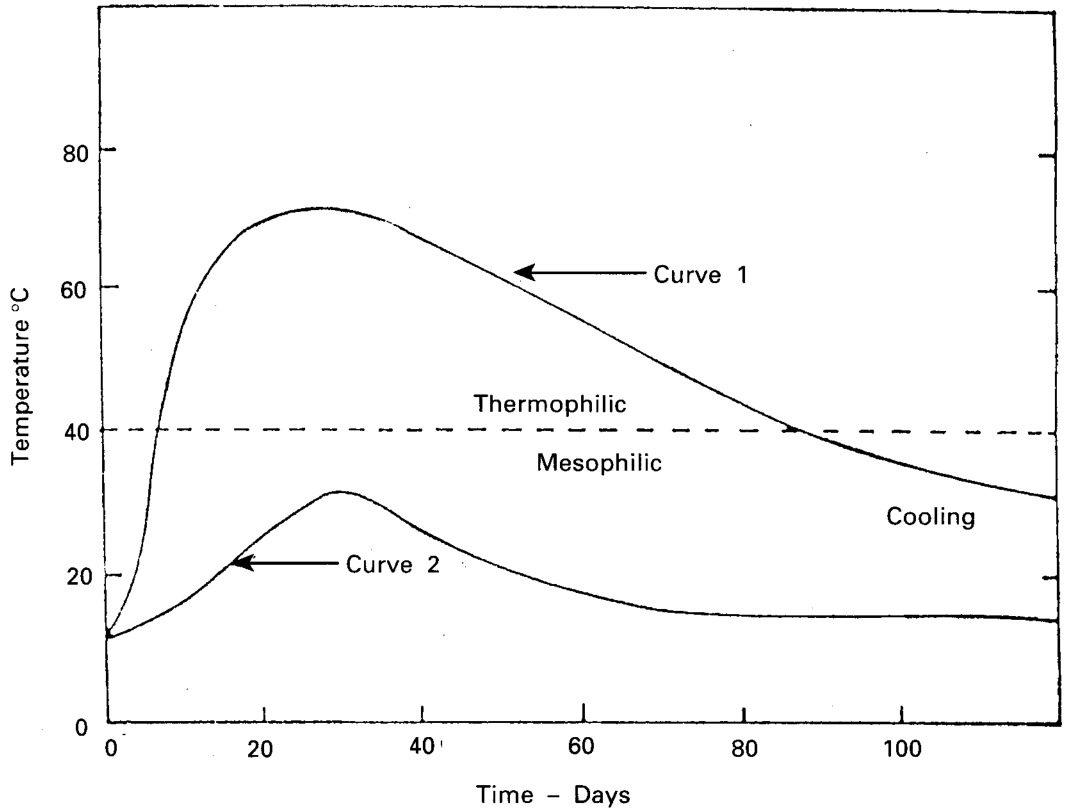

Fig. 3. Typical time-temperature relationship for composting organic wastes by the Beltsville Aerated Pile Method. Curve 1 indicates that conditions of moisture, temperature, C:N ratio, and aeration are at optimum levels for rapid aerobic, thermophilic composting. Within several days, the internal pile temperatures increase rapidly from the mesophilic (20 to 40°C) into the thermophilic (> 40°C) stage, after which the temperature begins to decline as available nutrients are depleted by the indigenous microorganisms. Curve 2 indicates what might happen when certain parameters are deficient or outside their optimum range, which would limit the growth and activity of microorganisms and adversely affect the desired time-temperature transition for successful composting.

Table 2. The value of some organic wastes based on their macronutrient content.

Organic Waste	Nutrients N	P	K	Value[1] ($/mt)
	%			
Cattle manure	4.4	1.1	2.4	23.47
Crop residues	1.1	0.2	2.0	8.44
Sewage sludge	4.0	2.0	0.4	21.40
Municipal solid waste	0.7	0.2	0.3	3.66

1 Value per kg of N, P, and K was set at $0.30, $ 0.37, and $0.20, respectively, based on average dealer prices/FOB of fertilizers at midwest terminal locations, December 1990

material. Barbarika *et al.* (1980) and Colacicco (1982) estimated that 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 year of application.

USE OF MUNICIPAL WASTES AS SOIL CONDITIONERS AND BIOFERTILIZERS

The two principal types of waste that have come with municipal development are sewage sludge and effluents, and solid waste or garbage. For centuries, municipal wastes have been used as soil conditioners and biofertilizers to enhance the productivity of agricultural land. During the last two decades, considerable research has been conducted to ensure that sewage sludge could be used safely and beneficially on cropland (USEPA 1989, Chaney 1990a,b). The current annual production of sewage sludge in the United States is about 8.0 million mt (dry weight), and more than 30% of this is being utilized beneficially on agricultural and nonagricultural land as compost, or by land spreading and liquid sludge infection (Parr and Hornick 1992a).

The production and disposal of municipal solid waste (MSW) in many countries, including the United States, has become an increasingly difficult problem, far greater than the disposal of sewage sludge. Currently the United States produces about 180 million mt (dry weight) of MSW, each year, and is expected to produce more than 200 million mt by the year 2000. Only 10% of this MSW is being recycled, while 80% goes into landfills, and 10% is incinerated (USEPA 1989). Paper, garden wastes, food waste and wood waste account for more than 60% of our MSW. Thus, under proper conditions this biodegradable fraction could be composted or co-composted for beneficial use as soil conditioners and biofertilizers (Parr and Hornick 1992a).

Research Needed to Enhance the Utilization of Municipal Wastes in Agriculture

The following research should be given high priority to optimize the safe and beneficial use of municipal wastes in agriculture:

- Develop technology for co-composting sewage sludge, municipal solid waste, and agricultural wastes that will ensure product quality and acceptance by farmers.
- Improve the agronomic value of municipal, industrial, and processing wastes as composted organic fertilizers by enriching or "spiking" them with chemical fertilizer.
- Inoculate finished compost or co-compost with cultures of beneficial microorganisms, to promote plant growth and suppress soilborne pathogens and diseases.
- Develop reliable methods of determining the maturity and stability of composts and co-composts from municipal wastes. These include simple chemical and physical measurements and plant bioassay procedures.

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 inoculants, organic amendments, and cultural and 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, and municipal wastes (both raw and composted) contain their own indigenous populations of microorganisms, and that these often have broad physiological capabilities. It is also known that when such organic wastes and residues are applied to soil, many of these introduced microorganisms can function as biocontrol agents by controlling or suppressing soilborne 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 (Baker 1968, Papavizas and Lumsden 1980, Kloepper *et al.* 1989).

Possible Mechanisms Induced with 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.
- *Parasitism*. Direct parasitic attack on soilborne plant pathogens by non-pathogens.
- *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, and have been largely unsuccessful for several reasons. Firstly, we did not thoroughly understand the individual growth and survival characteristics of each particular beneficial microorganism, including its nutritional and environmental requirements. Secondly, our knowledge of their ecological relationships and interactions with other microorganisms was lacking. And thirdly, 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. This very common observation is depicted in Fig. 4.

Higa and Wididana (1991) and Higa (1994) reported a unique approach in maximizing the beneficial effects of microbial inoculants, which is also shown in Fig. 4. Through repeated applications of the organic amendment, or mixed culture inoculant, while the level of microbial growth and activity is still high (i.e. well above the baseline), they can maintain a high inoculum density of the inoculated microorganisms for an extended period. This approach can help to ensure that the numbers of beneficial microbial cultures that promote plant growth and protection will remain high during the first three to four weeks after planting a crop. This is the period when young seedlings and plants are so vulnerable to environmental stresses (e.g., drought, heat, weeds, insects, and diseases). Also, it is when the greatest loss in potential crop yield and quality can occur. Once through this critical period, the treated plants are vigorous, and healthy, and can more easily cope with stress factors.

Research Needed to Enhance the Effectiveness of Microbial Inoculants in Agriculture

The following research should be given high priority in the attempt 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 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.

CONCLUSION

Alternative agriculture practices are vitally dependent upon the proper and regular additions of organic wastes and residues to soil. Some farming systems do not produce adequate amounts of on-farm organic wastes to enhance the essential attributes of soil quality, or to attain the goal of long-term agricultural sustainability. The rapidly increasing amounts of municipal wastes can provide an alternative, off-farm source of organic amendments that can be used safely and beneficially to increase the productivity, tilth, fertility and sustainability of our agricultural soils.

The quality and acceptability of many organic wastes, from both on-farm and off-farm sources, can be greatly enhanced through composting. Some wastes that are not suitable for composting because of a high C:N ratio or an excessive moisture content can be blended with other materials to improve their chemical and physical properties, and to optimize rapid aerobic, thermophilic composting of the mixture. The critical factors that affect the composting process and their interrelationships must be thoroughly understood to ensure optimum composting conditions and product quality. The value of organic wastes as biofertilizers and soil conditioners can be estimated in a number of ways, depending on the ultimate objective(s) in their use. Most of these values are cumulative and extend considerably beyond the first year of application.

Inoculants of mixed cultures of beneficial microorganisms have considerable potential for controlling the soil microbiological equilibrium and, thus, providing a more favorable environment for plant growth and protection. Research is needed to ensure a high level of consistency in performance and benefits, and to ensure adequate quality control with respect to inoculum density and activity.

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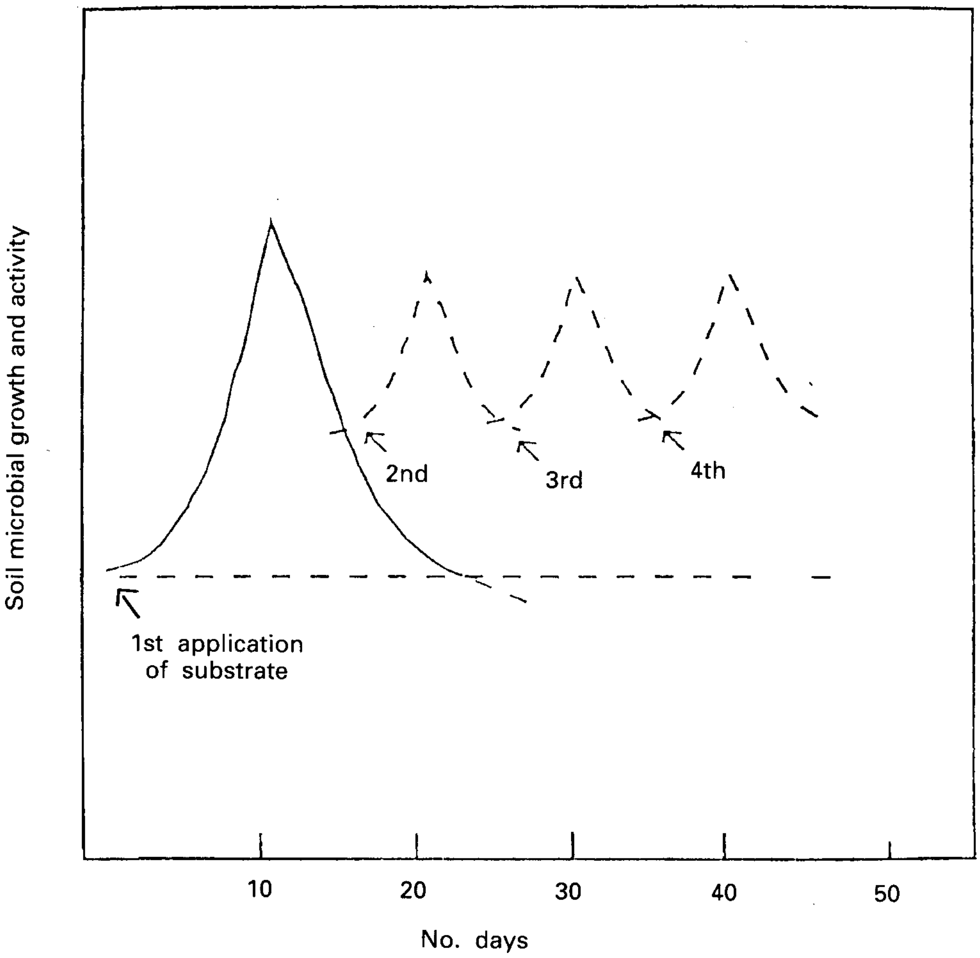

Fig. 4. Growth and activity of soil microorganisms after application of an organic amendment. The rate of utilization of substrate carbon as an energy source by the soil microflora and/or microbial inoculants is depicted by the solid line. The population of select microorganisms can be maintained at a high level by successive applications of the microbial inoculant and a carbon source as shown by the dotted lines.

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DISCUSSION

Dr. Hong raised the question of the effectiveness of inoculants, and pointed out that these often do not fulfill the claims made in advertisements. There have been efforts to evaluate the effectiveness of these products in Korea, but they included a wide range of materials and many brand names. So far, scientists testing the inoculants had been unable to recognize any marked effects from using them. He asked about the situation in the United States. Dr. Parr agreed that this is a difficult problem. He had himself spent a considerable amount of time evaluating products known as "soil activators", often with little or no positive results. He agreed that many products are being marketed with exaggerated claims, but had also seen promising results from some products. He informed the meeting about the consultative group known as APNAN (Asia-Pacific Natural Agricultural Network), which has evaluated soil inoculants in a number of Asian and Pacific countries since 1989. He suggested that since Korea is a member of APNAN, some cooperative work might be conducted to evaluate such products.

Dr. T.C. Juang asked about the extent of the support for organic farming by the United States government. Dr. Parr described the 1990 Farm Bill, which established a National Organic Certification Standards Board for farmers who wish to produce organically grown food. Dr. dela Cruz pointed out that many farmers in the United States had claimed that organic farming was the best method, but experience in the Philippines had shown that organic materials do not supply enough nutrients, and must be supplemented with a basal chemical fertilizer application. He emphasized the need for a balance between chemical and organic fertilizers. Dr. Parr agreed, and pointed out that this was also the viewpoint of the 1980 USDA Report and Recommendations on Organic Farming. The records of the Rothamstead Research Station in England and many other stations show that yields are highest when inorganic and organic fertilizers are used together. However, it is still not known to what extent farmers can cut back on the use of chemicals when they adopt improved farming methods. Certainly farmers in the USA are applying too high a level of chemical fertilizers and pesticides, according to Dr. Parr. He also pointed out that chemical pesticides are very expensive, and if yields fall by 10% when fewer chemicals are used, the net return may still be greater. It should be the goal of researchers all over the world to provide farmers with as many options as possible.

Dr. Zulkifli asked about the main constraint to using sewage sludge in compost, whether it was shortage of land or the need for a quick return on investment. He referred to the nationwide utilization of sewage sludge in Malaysia. Dr. Parr pointed out that problems arise very quickly when various wastes are disposed of indiscriminately in the environment. Even in Malaysia, some agroindustrial wastes were at one time being dumped in rivers, although there is now strict regulation. He recommended that the utilization of these materials should be considered before they become a major problem, and suggested that surveys should be carried out every five years or so, to find what materials are being generated by industry etc., and which of these are suitable for land utilization or reclamation purposes. Countries need to know what wastes are being produced in the agricultural, municipal and industrial sectors, whether they are available, and if they can be used safely and beneficially on land, especially agricultural land.

Professor Sung of Korea referred to the problem of overuse of organic materials, and pointed out that Korean farmers sometimes use 80 mt/ha or more for vegetables. He asked whether there was any data on how much organic matter could be applied, and what is the optimum rate. Dr. Parr agreed that too much organic fertilizer is undesirable, whether of compost or raw waste, and agreed that it is particularly common in vegetable production. In some countries the soil is even being used as a waste disposal system. If too much organic material is applied, nitrogen is nitrified into nitrate and its leaching potential is enhanced. To estimate the proper application rate, Dr. Parr recommended that the crop N requirement be calculated, based on the potential yield. Credit must be given for the N that has already been applied in the past, and a calculation made of how much will become available. Each crop has to be evaluated in this way. In the United States, N recommendations are based partly on nitrate measurements taken at 6-inch increments (15 centimeters) to a depth of four feet (1.3 meters). The amount of soil residual N is then subtracted from the total crop N requirement.