The Importance of Soil Microbiology in Agriculture

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Abstract

Applied soil microbiology in agriculture deals extensively with studies on the isolation, culture and use of Rhizobium spp. and mycorrhizae to improve soil fertility, plant growth and yield. A significant amount of the published literature on soil microbiology is devoted to these two groups of beneficial microorganisms. Soil biology has had a relatively small impact on agricultural practices in countries of the temperate regions where intensive farming is well-developed, and where soil biological activity is generally low. By contrast, the high biological activity of soils in tropical countries is the main factor which limits crop yields. Our studies on agricultural soils worldwide have shown that soil biological activity (as estimated by phosphatase activity) is dependent on climatic factors and geologic parent materials. In the tropics, soil biological activity is greatest in the root surface-rhizosphere region of plants and with various faunal associations. Our field work in Brazil has shown that soil biological applications were responsible for a two-fold increase in the yield of rice and soybeans.

Introduction

By the early 1900's, soil microbiology had experienced some success in developing legume inoculation technology for N-fixation with Rhizobium spp. and in furthering our knowledge of mineral nitrogen transformations. Except for some progress in elucidating details of the nitrogen cycle, the field of soil microbiology remained at the "test tube" level for more than 50 years with little progress in the development of practical applications for agriculture.

The situation was further compounded beginning in the 1950's with outstanding advances in plant genetics and the development of high-yielding varieties that were grown with chemical fertilizers and an expanding arsenal of new pesticides. Farmers soon realized that their use of improved Rhizobium strains might increase crop yields by 20 percent, while chemical fertilizers could increase yields by 100 percent or more. This is why some farmers still use up to 90 kg of N/hectare on such legume crops as soybeans and field beans.

With the adoption of high-yielding varieties and expanded use of agrichemicals farmers worldwide, but especially in developed countries, intensified their production of row-crops and cash grain crops and virtually abandoned their use of sod-based crop rotations. Consequently, from the 1950's to the 1980's this type of farming led to some of the most serious soil erosion, land degradation and loss of soil productivity that was ever recorded. As a result, most countries experienced severe environmental pollution from sediment and agrichemicals and much of their farmland was rendered infertile and unproductive.

By the early 1980's there was a growing awareness that soil microbiological applications and practices were urgently needed to restore the fertility, productivity and sustainability of degraded agricultural soils. This paper reports how certain parameters such as soil microbial activity and soil microbial biomass, which are highly correlated with soil quality, can be used as vital indicators of soil fertility and productivity.

Methods for Determining Soil Microbial Biomass and Activity

The various methods that can be used to measure soil microbial biomass and activity are illustrated in Figure 1 according to Paul and Clark (1989).

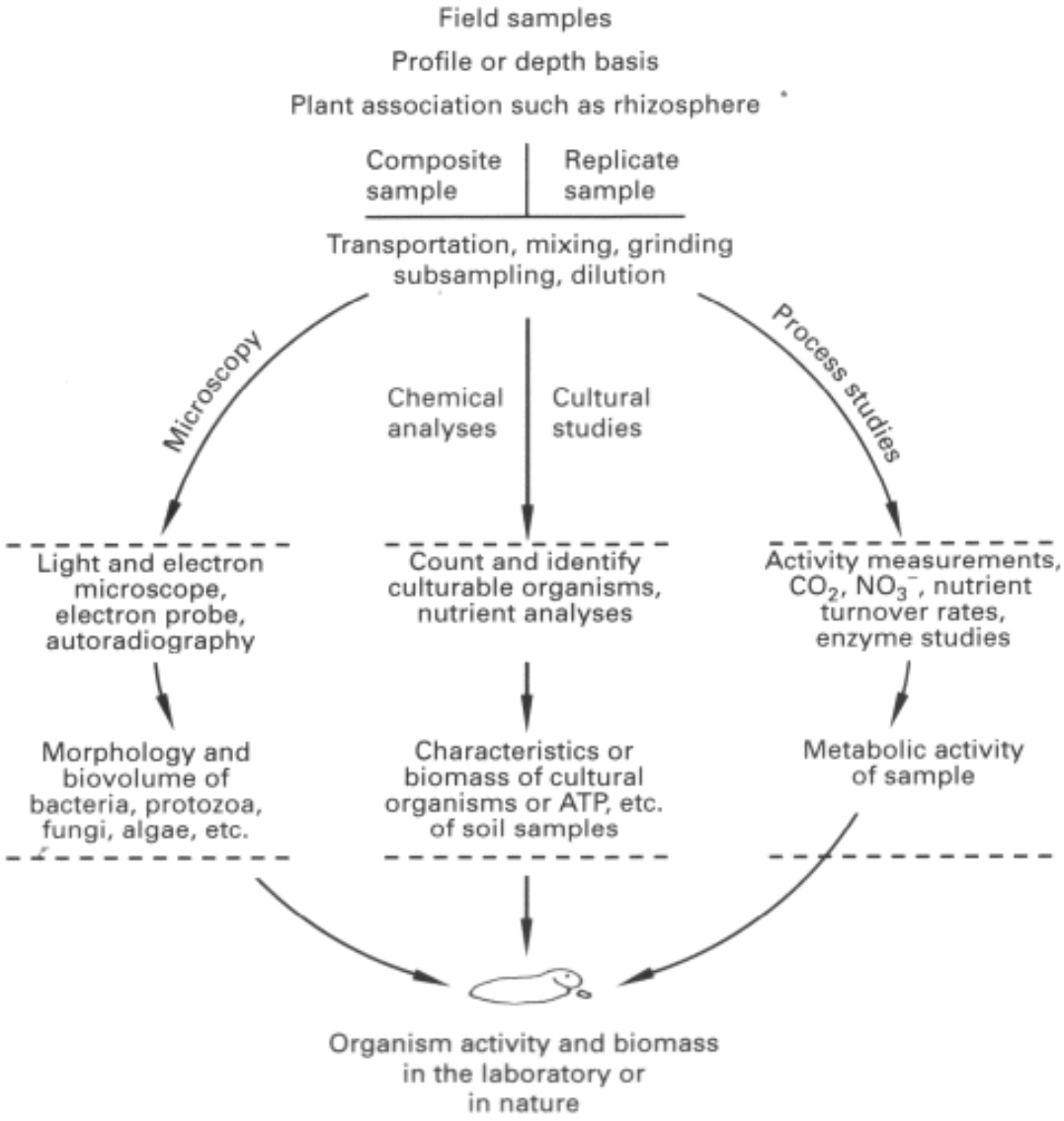

Figure 1: Methods for Determining Microbial Biomass and Activity (Paul and Clark, 1989)

Soil Microbial Biomass

The microbial biomass of a soil can be measured by direct microscopic methods (e.g., thin section and immuno-fluorescent techniques); direct counting methods; chloroform fumigation; and adenosine triphosphate (ATP). Jenkinson and Ladd (1981) compared the results of three methods for estimating soil microbial biomass which is reported in Table 1.

Table 1: Estimates of Soil Microbial Biomass Carbon by Three Methods (Jenkinson and Ladd, 1981)

Field Source	Biomass		
	Chloroform Fumigation	Direct Count	ATP Method
	($\mu g\ g^{-1}$ soil)		
Continuous Wheat plus manure, England	560	500	430
Continuous Wheat no manure, England	220	170	170
Continuous deciduous wood, England	1230	1400	1040
Acid deciduous wood, England	50	300	470
Old grassland, England	3710	2910	-
Secondary rain forest, Nigeria	540	390	-

Soil Microbial Activity

The methods used to characterize soil microbial activity are somewhat specific and can involve the measurements of respiration rates with carbon dioxide evolution; nitrification rates with production of nitrate; nutrient or substrate consumption, or turnover rates; and the use of enzymes to study metabolic reaction rates (Tabatabai, 1982; Maire, 1987).

One of the most reliable and precise measurements of soil microbial activity is the alkaline phosphatase assay method reported by Tabatabai (1982). It is based on colorimetric estimation of p-nitrophenol that is released when the soil is incubated with buffered sodium p-nitrophenyl phosphate. The rate and extent of release of p-nitrophenol is a direct measure of alkaline phosphatase activity. This method was selected because higher plants do not contain this enzyme. Thus, alkaline phosphatase activity in soil appears to be derived exclusively from soil microorganisms. This also allows one to make a distinction between the type of phosphatase activity of roots and the alkaline phosphatase activity of microorganisms.

Ultimate interpretation of soil microbial activity is best made with a knowledge of soil chemical and physical properties. For example, there are strong correlations between phosphatase activity and the soil clay content, and between phosphatase activity and the soil carbon content.

Results and Discussion

The following results deal mainly with studies that have investigated the effects of various soil management practices on microbial activity. Most results were obtained using the alkaline phosphatase assay method and report microbial activity in terms of micrograms of p-nitrophenol released per gram of dry soil per hour (or, µg pnp/g dry soil/ hour).

The data reported in Table 2 show that microbial activity decreases with increasing soil depth. Also, it is highest in the topsoil of undisturbed forest land compared with a cultivated vineyard. The comparatively low activity at the 0-5 cm depth of the vineyard soil is likely due to dessication effects of tillage and possibly adverse effects of pesticide usage.

Microbial activity can change rapidly from soil management practices as shown in Tables 3 and 4. Generally, microbial activity is higher in calcareous soils than acidic soils because they provide more favorable conditions to support a highly diverse population of microorganisms. The addition of organic amendments substantially increases the microbial activity of soils because they provide a source of carbon, energy, and nutrients to enhance the growth, activity and numbers of microorganisms. Interestingly, the application of swine manure depressed the microbial activity, although optimum levels were obtained with other sources of organic amendments including compost, green manure and grassland.

Doran (1980) reported a useful way of comparing the effects of tillage on various microbial groups by calculating the average ratios of different populations found under no-tillage and conventional tillage systems (Table 5) expressed as NT:CT. The data reported in Table 6 show that microbial activity in a no-tillage system is substantially higher than with conventional tillage, especially in the plow layer and to a depth of 20 cm.

Table 2: Effect of Soil Depth on Microbial Activity in Calcareous Soil of Burgundy under Forest and Vineyard.

Soil Depth (cm)	Forest	Vineyard
	(µg pnp/g dry soil/ hour)	
0-5	820	243
5-10	647	469
10-20	530	504
20-40	360	250
40-80	220	210

Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Table 3: Effect of Chemical Fertilizer and Organic Amendments Applied to Calcareous and Acidic Soil on Microbial Activity.

Treatments	Calcareous	Acidic
	(µg pnp/g dry soil/ hour)	
Chemical Fertilizer	765 ± 25	110 ± 8
Green Manure	1010 ± 22	82 ± 5
Manure (35 t/ha)	824 ± 53	120 ± 7
Compost (4 t/ha)	939 ± 24	125 ± 13

The organic matter content of the calcareous soil was 6.9% and the acidic soil was 1.6%. Both soil were cropped to corn.
Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Table 4: Effect of Soil Management Practices on Microbial Activity.

Treatments	Soil Microbial Activity (µg pnp/g dry soil/ hour)
Corn + Swine Manure (50 m^3/ha)	154 ± 14
Bare soil	172 ± 4
Corn + Cow Manure (17 t/ha)	195 ± 4
Corn + Cow Manure (34 t/ha)	269 ± 5
Corn + NPK	277 ± 18
Corn + Compost (10 t/ha)	331 ± 7
Grassland (4 years) + NPK	353 ± 4

Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Table 5: Average Ratios of Different Microbial Populations Found under No-Tillage (NT) and Conventional Tillage (CT) Systems at Two Soil Depths (Doran, 1980)

Microbial Group	Soil Depths (cm)	
	0-7.5	7.5-15
	(NT:CT)	
Aerobic bacteria	1.41	0.68
Facultative anaerobes	1.57	1.23
Actinomycetes	1.14	0.98
NH_4^+ oxidizers	1.25	0.55
NO_2^- oxidizers	1.58	0.75
Fungi	1.57	0.76

Table 6: Effect of Tillage System and Soil Depth on Microbial Activity in Cultivated Calcareous Soil.

Soil Depth (cm)	Conventional Tillage	No-Tillage
	(µg pnp/g dry soil/ hour)	
0-5	280	557
5-10	339	483
10-20	299	390
20-60	243	255
60-100	188	192

Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Soil microbiological applications in agriculture have often been neglected in temperate zone countries in favor of chemical fertilizers. One reason for this is that microbial activity in temperate zone soils is 3 to 10 times lower than in tropical soils. The high level of microbial activity that dominates various reactions and processes of tropical soils is fundamental to the development of a long-term sustainable agriculture.

Tropical soils are often ferrallitic - high in their iron and aluminum content; low in cation exchange capacity; low in natural fertility; and unproductive for intensive agriculture without substantial inputs. The indigenous vegetation consists of tall trees with deep roots which can recover and recycle nutrients that have leached under high rainfall conditions, thereby returning them to the canopy. Thus, these tropical forests are a vital component of a biogeochemical cycle that helps to maintain a basic level of fertility in these tropical soils. Because of high rainfall, humidity, and temperature, tropical soils have a much higher rate of organic matter mineralization compared with temperate zone soils. According to Paul and Voroney (1984), the soil carbon turnover rate for tropical soils in Brazil could be as high as 50 percent a year compared with some temperate zone soils in Canada of less than 3 percent.

Table 7 shows that the microbial activity of the ferrallitic soils of Mato Grosso (Brazil) decrease rapidly after deforestation, and also decrease with soil depth. Seguy and Bouzinac (1994) reported that certain deep-rooted plants can help to restore microbial activity of the topsoil by recycling leached plant nutrients back to the surface. A partial explanation of these results can be derived from the data presented in Table 8. While the microbial activity of this ferrallitic soil has declined to a very low level, the localized soil habitats including the rhizosphere soil and termite feces are significantly higher. The deep-rooted "pump" plants have produced biomass and nutrients that have enhanced the soil rhizosphere activity and allowed termites to return. These results confirm the findings of Van der Meulen (1977) on restoration of tropical soils.

Table 7: Effect of Management Practices on Microbial Activity in Various Depths of a Ferrallitic Soil of Mato Grosso (Brazil).

Soil Management	Soil Depths					
	0-5	5-10	10-20	20-40	40-100	100-200
	(µg pnp/g dry soil/ hour)					
Forest	629	208	190	114	10	5
Cerrado	159	138	98	72	39	27
Grassland (15 yr.)	149	106	75	89	41	10
Corn (after forest)	152	75	80	11	6	3
Rice/soybean (15 yr.)	13	12	9	10	8	9
Deep-rooted plants	202	50	40	38	35	10

The Data reported for corn was obtained during the first year following deforestation. Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Table 8: Effect of Soil Habitat on Microbial Activity of a ferrallitic Soil of Mato Grosso (Brazil) Vegetated by Savanna.

Soil Habitat	Microbial Activity (µg pnp/g dry soil/ hour)
Soil	10 ± 4
Rhizosphere soil	93 ± 12
Termite feces	278 ± 30

Microbial Activity is based on measurement of alkaline phosphatase activity (µg p-nitrophnol released/g dry soil/hour).

Conclusion

Measurement of such biological parameters as microbial biomass and microbial activity are not included today in standard soil analysis. Yet, these parameters are basic to the development of a more sustainable agriculture. The observation and report of "soil fatigue" worldwide is likely the result of the decline in these biological parameters and the associated decrease in soil productivity (Worldwatch Institute, 1994). With the increasing awareness of the importance of soil microbiology in agriculture it is virtually assured that biological parameters will become a vital component of future soil analysis and diagnosrs.

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