Effect of EM and Green Manure on Soil Productivity in Brazil

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Abstract

Applications of EM and green manure increased crop productivity while soil erosion and the incidence of plant diseases declined. A farm with compacted soil, severe soil erosion and low crop productivity solved these problems by using EM for 2 to 3 years. Soils with and without EM were compared for a) compaction, b) basic water infiltration rate (BWZR), c) paint penetration, and d) soil porosity. Despite 2 to 4 annual vegetable cropping cycles, the soils treated with EM had higher particle aggregation, porosity, and BWIR; lower disease incidence; and increased crop productivity and profitability than soils without EM. Lower soil compaction was statistically significant and an increase in BWTR from 232 to 1762 percent was obtained in the areas treated with EM as compared with the controls.

Introduction

Several farmers observed that after using Effective Microorganisms (EM) and green manure as soil amendments and spraying lettuce crops with EM for 2 to 3 years there was a decline in soil erosion and in the amount of water needed for irrigation, and a decrease in the incidence of lettuce leaf drop (*Sclerotinia sclerotiorum*). A farmer who had experienced these problems for more than 20 years and had overcome them by adopting the new technologies was selected for further study; also, the soil on his farm had changed from inductive to suppressive for *S. sclerotiorum*.

According to the literature, the utilization of green manure improves the soil physical properties by enhancing soil aggregation, porosity, and fertility, all of which help to control erosion (Faeth et al., 1991). Abawi and Grogan (1979) and Steadman (1979) suggest that the changes in soil physical properties from adding green organic matter may interfere in the formation and production of apothecia in *S. sclerotiorum*. A reduction in irrigation in the final cycle of lettuce and bean crops is an effective and recommended means of controlling the disease (Steadman and Nickerson, 1975; Steadman, 1979).

Several authors have demonstrated that after releasing the ascospores there is no germination or infection without an external source of energy (Lumsden, 1979; Purdy, 1958). Since saprophytic microorganisms compete for these energy sources, it is possible to control infection by means of epiphytic microflora (Tokeshi, 1991). The available information indicates that soil physical properties contribute to the suppression of *S. sclerotiorum*.

A holistic study was conducted to determine how EM interacts with soil physical, chemical and microbiological properties. This paper deals only with the effect of soil physical properties.

Physical analyses were made to confirm the farmer's observations that EM application increased soil aggregation, decreased erosion and compaction, reduced the irrigation requirement, and enhanced the soil's capacity to suppress lettuce leaf drop disease. Consequently, a farm that was failing because of low agricultural productivity had become productive and profitable again.

Materials and Methods

Farmers that used EM with green manure and crop residues noticed an improvement in the soil physical properties, a reduction in soil erosion and a decline in the incidence of lettuce leaf drop disease. A farm that reported such beneficial effects of EM, and where the irrigation frequency had dropped from 2 to 3 times a week to one, was selected for the study. These changes had occurred after using EM with green manure from vegetable crop residues and weeds for a period of 2 to 3 years.

According to the farmer, the farm had received chemical fertilizers, herbicides, fungicides, and insecticides for 20 years; the land had been subject to severe soil erosion and compaction, plant pests, and diseases. The resulting low agricultural productivity had caused the farmer to become bankrupt.

The farm had always been cultivated with 2 to 4 annual vegetable cropping cycles with 4 to 8 tillage operations using a rotavator or plow; this regime facilitated the formation of a compacted and less permeable layer below the arable soil layer. To verify these reports, 4 plots of 1 hectare each were selected: 2 plots (M-1 and M-3) with EM application and 2 plots with a similar soil but without EM. The plots were prepared for cereal cultivation in the interrows of an orange orchard alongside area M-1, and for corn in rotation with pasture alongside area M-3.

The orchard area was separated from the M-1 plot by a 6-meter strip of banana and eucalyptus hedge and a road which was at a slightly higher level than M-1. The corn-pasture area was separated from M-3 by a natural drainage canal approximately 50 m wide. Both areas have the same elevation and soil type. The analyses of soil physical and chemical properties are shown in Tables 1 and 2.

In order to identify the causes for the reduction in erosion and the irrigation requirement, the following properties were determined: a) soil compaction with an impact penetrometer, b) basic water infiltration rate (BWIR), c) paint penetration into the soil, and d) soil porosity.

Table 1. Physical Characteristics of Soils in the Experimental Areas.

Area	Tillages (No.)	Soil Depth (cm)	Mechanical Analysis			Textural Class
			Sand (%)	Silt (%)	Clay (%)	
M-1	4 to 8	0 to 15	51	11	38	Sandy clay
		15 to 45	44	16	40	Clay loam
		45 to 75	44	17	39	Clay loam
Orchard	1	0 to 15	41	11	48	Clay
		15 to 45	39	8	53	Clay
		45 to 75	35	13	52	Clay
M-3	4 to 8	0 to 15	19	8	73	Clay
		15 to 45	29	9	62	Clay
		45 to 75	27	14	69	Clay
Corn- Pasture	0	0 to 15	16	8	76	Clay
		15 to 45	13	6	81	Clay
		45 to 75	8	8	84	Clay

M-1 and M-3 areas had 2 to 4 annual vegetable cropping cycles, Orchard area contained a mixture of weeds Corn-pasture area was a rotation of these crops

Table 2. Chemical Characteristics of Soils in the M-1 and M-3 Areas Treated with EM and the Orchard and Corn-Pasture Areas without EM.

Area	Soil Depth (cm)	pH ($CaCl_2$)	OM (%)	P (mg dm^{-3})	K	Ca	Mg	H+Al	CEC	Base Sat. (%)
					(cmol$_c$ dm^{-3})					
M-1	0 to 15	4.4	2.6	85	0.42	3	1	8	12.4	35
	15 to 45	3.8	1.3	12	0.14	0.8	0.4	7.2	8.5	15
	45 to 75	3.8	1.1	6	0.12	0.7	0.3	0.2	8.3	13
Orchard	0 to 15	4.4	2.6	28	0.13	2.2	0.5	10.9	13.7	20
	15 to 45	4.1	1.6	10	0.12	0.4	0.2	7.2	7.9	9
	45 to 75	4.2	1.1	19	0.1	3.3	0.8	5.2	9.4	45
M-3	0 to 15	5	3.9	192	0.44	4.9	1.7	5.2	12.2	57
	15 to 45	4.7	3.4	31	0.32	3.9	1.4	6.4	12	47
	45 to 75	4.4	1.9	4	0.2	1	0.5	4.7	6.4	27
Corn- Pasture	0 to 15	3.7	3.8	7	0.14	1.3	0.2	8	9.6	17
	15 to 45	4.2	2	6	0.11	2	0.3	8	10.4	23
	45 to 75	4.8	1.7	16	0.12	2.2	0.3	3.8	6.4	41

M-1 and M-3 areas had 2 to 4 annual vegetable cropping cycles.
Orchard area contained a mixture of weeds.
Corn-pasture area was a rotation of these crops.

Soil Compaction

Soil compaction was assessed by using an impact penetrometer (Stolf *et al*., 1983); this equipment permits more than 80 determinations per day with adequate precision. Data were collected from 8 to 15 points for each of the assessed areas. Because of differences in soil utilization and preparation, a 20-cm superficial layer of soil was discarded and the compaction of the non-arable subsoil was statistically analyzed; averages were compared by the F test recommended by Pimentel Gomes (1978).

Since evaluations of soil compaction are affected by soil moisture, samples were collected from 5 points at different depths in the areas of comparison.

Basic Water Infiltration Rate (BWIR)

Recommendations of Agriculture Handbook No. 60 (Richards, 1954) were used to determine the BWIR at three points in each of the areas under study, and the averages were calculated for comparison. Difficulties in the method did not permit using a high number of replications.

Paint Penetration Determination

To assess the rate and extent of water infiltration into the soil, latex paint diluted at a ratio of 1:3 was applied in the external ring of the infiltrometer used for the BWIR determinations. With the soil at field capacity, the diluted paint was allowed to infiltrate for 40 minutes and the infiltration depth was evaluated by digging 1.7 m trenches at the infiltration points (Bernardo, 1984).

Soil Porosity Determination

The tension table method described by Bernardo (1984) and Richards (1954) was used for determining soil porosity. Based on the mean compaction curves of the penetrometer, three depths were selected to measure the percentage of macropores and micropores in the layers which might present major problems. These determinations were replicated at 3 points and 3 depths, and the averages were compared without statistical analysis.

Results

Penetrometer Measurements in Area M-1

Soil compaction as measured by the impact penetrometer indicated that the M-1 plot was in

Table 3. Average Compaction of Subsoil in the M-1Area Treated with EM and the Orchard Area without EM.

Soil Depth (cm)	Soil Area	Strokes per Decimeter	Compaction Increase (%)
21-23	Orchard	3.7b	317
	M-1	0.9a	0
23-25	Orchard	3.8b	159
	M-1	0.3a	0
25-27	Orchard	3.8b	111
	M-1	1.8a	0
27-29	Orchard	3.4b	93
	M-1	1.8a	0
29-31	Orchard	3.4b	118
	M-1	1.5a	0
31-33	Orchard	3.1b	85
	M-1	1.7a	0
33-35	Orchard	3.1b	79
	M-1	1.7a	0
35-37	Orchard	2.9b	64
	M-1	1.8a	0
37-39	Orchard	2.6b	33
	M-1	2.0a	0
39-41	Orchard	2.7b	42
	M-1	1.9a	0

Column means having different letters are significantly different at the 1% level of probability ($P<0.01$).

excellent condition without clay deposition below the arable layer. This became more evident when the orchard soil, which shows residual compaction at a depth of 20 to 25 cm, was compared with soil in the M-1 plot. Average data for the 15 points per treatment and percentages of increase in compaction are shown in Table 3. The top 20-cm layer was discarded in the statistical analyses because the orchard area was not cultivated as was the M-1 area. The results showed that compaction of the subsoil in the orchard area was significantly greater than for the M-1 area.

Penetrometer Measurements in Area M-3

Evaluations of compaction for the M-3 and pasture-corn areas showed that the soils are in excellent condition without a compacted layer because of recent plowing. The rather compacted layer at the soil surface of the pasture was the result of animal trampling. Data in Table 4 show that the M-3 soil was significantly better aggregated than the pasture-corn area at the 21- to 25-cm depths.

The compaction curve for the pasture-corn area showed that one corn cultivation cycle broke the superficial crust of the pasture but did not substantially change compaction at the 21- to 25-cm depths. At greater depths, the three areas were similar with regard to compaction. Calculating the compaction percentage increase at the 21-23 and 23-25 cm depths, the variation was from 833 to 38 percent, respectively.

Table 4. Average Compaction of Subsoil in the M-3 Area Treated with EM and the Corn-Pasture Area without EM.

Soil Depth (cm)	Soil Area	Strokes per Decimeter	Compaction Increase (%)
21-23	Pasture	2.3b	833
	Corn	2.2b	798
	M-3	0.2a	0
23-25	Pasture	2.5b	50
	Corn	2.3b	38
	M-3	1.7a	0
25-27	Pasture	2.6b	19
	Corn	2.8b	30
	M-3	2.2a	0

Column means having different letters are significantly different at the 1% level of probability ($P<0.01$).

Water Infiltration into the Soil

An attempt was made to characterize the soils by their BWIR. Soils aggregated by action of microorganisms showed a higher resistance to erosion, excess water infiltration, and less surface drainage. BWIR averages are shown in Table 5. The data indicate that the BWIR's are higher in areas M-1 and M-3 than in the control areas and the percentage increases were 232 and 1762 percent for areas M-1 and M-3, respectively. Because of difficulties in determining the BWIR, the data were not sufficient to permit an analysis of variance.

Table 5. Basic Water Infiltration Rate (BWIR) of Soils in Areas Treated with and without EM.

Area	EM Applied	BWIR (cm h^{-1})	Increase in BWIR (%)
M-1	yes	26.7	232
Orchard	no	8.9	0
M-3	yes	49.2	1762
Corn-Pasture	no	2.7	0

The M-1 and M-3 areas were amended with green manure organic matter.

Since rainfall rates of 5 cm per hour or greater may occur, erosion can be expected in the corn and pasture areas. In the orchard area, because of the maintenance necessary to control invading weeds, the soils were more highly aggregated; however, erosion may occur when rainfall rates reach 10 cm per hour. The data corroborate the farmer's observations that there was no water accumulation on the soil surface during sprinkler irrigation and that erosion ceased with the application of EM and green manure.

Paint Penetration into the Soil

Latex paint applied to the soils visualized the course and depth of infiltrating water. In soils treated with EM, the colored soil cylinder was more uniform and reached a greater depth in 40 minutes. In area M-3 the paint formed a uniform cone which reached a depth of 112 cm, whereas in the corn area the colored cone was not uniform and reached a depth of 36 cm only. In area M-1 the penetration cone reached 65 cm.

Soil Porosity Determination

Porosity evaluations of soils with and without EM showed that areas M-1 and M-3 had a higher percentage of macropores than the orchard, and corn-pasture areas (Table 6). In the 6- to 10-cm depth layer, the application of green organic matter apparently increased macroporosity by 144 and 145 percent. At the 20- to 24-cm depth, the M-1 and M-3 soils showed an increase in macropores of 50 and 80 percent, respectively, compared with the orchard, and corn-pasture soils that showed no increase. At the 36- to 40-cm depth, only the M-1 soil showed an increase in macropores; the corn-pasture area showed a macro-porosity 25 percent higher than the area treated with EM (M-3).

The results of apparent and real density evaluations of soils did not show any effect of EM on these characteristics, which indicates that either such parameters are not affected by EM treatment or the number of replications was not sufficient.

Table 6. Average Soil Porosity of Areas Treated with and without EM and Percentage Increase in Macropores.

Area	EM Applied	Depth (cm)	Macropores (%)	Micropores (%)	Total Porosity (%)	Bulk Density (g cm^{-3})	Macropore Increase (%)
M-1	yes	6-10	11	38.2	49.2	1.26	145
		20-24	6.6	41.5	48.1	1.41	50
		36-40	4.7	42.8	47.5	1.4	75
Orchard	no	6-10	4.5	47.9	52.4	1.33	0
		20-24	4.4	53	57.4	1.23	0
		36-40	2.7	47.3	50	1.3	0
M-3	yes	6-10	19.2	44.1	63.3	0.94	144
		20-24	4.8	52.8	57.6	1.16	80
		36-40	3.9	57.6	61.5	1.11	-25
Corn-Pasture	no	6-10	7.9	53.9	61.8	1.01	0
		20-24	2.6	55.8	58.4	1.08	0
		36-40	5.2	55.3	60.5	0.99	0

The M-1 and M-3 areas were amended with green manure organic matter.

Discussion

Because of the cost and difficulty in evaluating the physical characteristics of the soils, only the penetrometer was used for several replications. Data with other methods of analysis were used to confirm or to reinforce the information obtained with the penetrometer. Physical evaluations should help to determine whether a soil that is inducive of lettuce leaf drop disease can become suppressive to the disease through various cultural and management practices. Microbiological evaluations with *Sclerotinia* are underway to complement the soil physical and chemical data.

The decision to conduct the soil physical studies was based on the fact that the soil environment is responsible for the survival of the pathogen, i.e., production of the sclerotia, apothecia, and ascospores of *Sclerotinia*, which is the causal agent of lettuce leaf drop (Abawi and Grogan, 1975, 1979; Adams and Ayres, 1979; Adams and Tate, 1976; Chet and Henis, 1975).

Observations on irrigation and erosion indicated that the physical properties of the soil had changed which allowed better plant rooting, increased infiltration and storage of water, and improved nutritional conditions for the plant; these changes were reflected in the incidence of leaf drop disease of lettuce. The interdependence between the environment, pathogen, and host makes the problems complex and interrelated, and therefore, can only be evaluated from a holistic point of view (Henderson, 1962; Honda and Yumork, 1977; Abawi et al., 1975; Abawi and Grogan, 1979).

Soil Compaction

Measurements of soil compaction with the impact penetrometer were very useful and inexpensive because of the large number of points that could be evaluated in a relatively short time. The results indicate that area M-1, even though intensively cultivated, had not developed a clay pan below the plow zone. Contrary to what was expected, the 21- to 41-cm layer was less compacted than the adjoining area that was planted to grass with an occasional cultivation in the interrows.

Although the orchard is more than 10 years old, the soil still showed a residual compaction at the 20- to 30-cm depth because of earlier tillage practices. The soil physical properties can be improved with a grass cover; however, the application of EM and green manure (crop residues) apparently exceeded the soil's regenerative capacity with grass cover alone.

Penetrometer measurements showed that the M-3 soil was less compacted than the control soils (corn and pasture) which had a residual compaction at the 21- and 25-cm depth. At greater depths, the three soils showed similar compaction, very much like that of virgin forest soils.

Intensive soil tillage with a rotavator 4 to 8 times a year will soon destroy soil aggregates and begin to develop a compacted layer below the plow zone which has occurred in previous years. However, the application of EM to soil and crop foliage and the use of organic amendments such as green manure and crop residues, have prevented these degradative processes from occurring.

Water Infiltration in the Soil

The determination of BWIR is an indispensable parameter for irrigation and erosion control. The result is influenced by soil microbiological activity which, along with soil chemical properties, is responsible for the production of humic acid, fulvic acid, and polysaccharides (Hayes, 1986). These organic compounds cause the mineral particles of the soil to form aggregates and give rise to the pores where air and water remain.

An increase in BWIR accelerates drainage, rapidly decreases the water in the soil surface layer, and reduces to a minimum the time which the soil surface remains saturated. When the 3 to 4 surface centimeters of the soil are dry, the formation of fungal apothecia and sclerotia, and their germination are prevented which interrupts the life cycle of the pathogen (Abawi and Grogan, 1979).

Paint Penetration into Soil

The utilization of latex paint has been recommended as a tracer of biological routes in the soil (Bernardo, 1984) and has been shown to be adequate for tracing water courses in the soil; it also makes the aggregates visible at great depths. The fact that the colored cones of soil were more uniform in soils M-1 and M-3 than in the control areas shows that the aggregate distribution and paint transmission were higher in soils M-1 and M-3. This response was reflected by the depth of paint penetration, i.e., 36 cm in the corn area and 112 cm in M-3. Depth gain was 211 percent in the M-3 soil.

Soil Porosity Determination

Soil porosity determinations are directly related to BWIR and soil aggregation. Percolation of gravitational water in the soil occurs in pores with a diameter greater than 50 μm. The pores that retain water available to the plant have a diameter that varies between 0.5 and 50 μm; pores smaller than this are considered micropores and do not participate in soil drainage nor do they provide water to plant roots (Hayes, 1986).

Pores occur between and within aggregates. It is their size that determines a higher or lower porosity; aeration; drainage; BWIR; available water; and the type, number, and activity of soil microorganisms. The maintenance of intact aggregates is an essential part of good soil management and helps to prevent the formation of plow pans and clay pans that can obstruct pores below the arable layer.

Soil porosity measurements at depths of 6-10, 20-24, 36-40 cm in the M-1 area treated with EM showed that the macropores had increased by 145, 50 and 75 percent, respectively. Since the deep non-arable layer controls water infiltration, an increase of 50 and 75 percent in macroporosity is conducive to rapid drying of the soil surface. Apothecia formation occurs at soil depths of 0 to 3 cm, thus the increase in porosity and rapid drying of the soil surface would likely induce changes in the life cycle of *S. sclerotiorum* by preventing the formation of apothecia (Abawi *et al*., 1975; Saito, 1973; Steadman, 1979).

Relationship of Soil Physical Properties to the Incidence of Lettuce Leaf Drop Disease

Grogan (1979) concludes that the control of lettuce leaf drop disease has essentially failed because we know so little about how the fungal pathogen, *S. sclerotiorum*, is induced or suppressed in the soil. He also states that soil chemical and physical properties are likely to exert considerable influence in either of these processes.

Our results have shown that soil treated with EM and amended with green manure, followed by foliar application to the crop, vastly changed the physical properties of the soil. BWIR which is capable of causing rapid drainage of irrigation and rainwater increased dramatically from these treatments. This would likely hasten the rate of drying of the soil surface layer and prevent extended periods of waterlogging.

According to Abawi and Grogan (1979), the formation of apothecia in *S. sclerotiorum* occurs under the following conditions:

- Sclerotia must remain buried and moist to undergo "conditioning" in order to form apothecia.
- The "conditioned" sclerotia only produce apothecia if buried to a maximum of 3 cm.
- The soil must be covered to a large extent by crop residues or growing plants to prevent rapid surface evaporation and drying.
- The soil must be kept at or near saturation by irrigation or rainfall for at least 10 days; if the soil partially dries, apothecial formation is injured.

The physical-chemical properties of the disease-suppressive soils M-1 and M-3 (both treated with EM) had excellent drainage which prevented saturation of the surface soil layer. Since there is no dense layer and the infiltration rate is high, rain and irrigation water infiltrate quickly, thus preventing erosion as reported by the farmer.

Soil depth and structure allow for greater water storage, as measured by total and macropore porosity. Increased water storage results in a decline in irrigation frequency from 2 to 3 times a week (conducive to lettuce leaf drop), to once a week (soil becomes disease-suppressive). Thus, reduction in irrigation frequency is one of the main means of controlling lettuce leaf drop since it prevents the formation of apothecia in the soil.

Since EM was applied weekly or bi-weekly, it is likely that the saprophytic microorganisms propagated on the plant surfaces by utilizing sugars, amino acids and mineral salts leached from the plant. On the other hand, the buds were pre-colonized (Tokeshi, 1991). When leaves and other organs begin to senesce, the EM microorganisms colonize and decompose the tissues, thereby utilizing most of the available carbon and energy sources on the surface. Consequently, if any apothecia and ascospores are eventually produced in the field or in nearby non-suppressive areas and the ascospores reach susceptible plant parts, they rarely germinate to cause an infection because of the lack of available carbon and energy sources for development (Abawi *et al*., 1975; Lumsden and Dow, 1973; Lumsden, 1979; and Purdy, 1958). Therefore, the absence of erosion and the reduced irrigation frequency are indicators that corroborate the changes in the soil and the microbial environment and that, associated with the antagonistic microflora an fauna, make the soil suppressive to. *S. sclerotiorum*

Summary and Conclusions

The results show that by using EM and green manure it was possible to change a soil that was inductive to lettuce leaf drop disease into a soil which was suppressive to that disease in 2 to 3 years. Faeth *et al*. (1991) reported similar changes by using crop rotations and no tillage practices for controlling erosion at the Rodale Research Center, Emmaus, Pennsylvania, USA; erosion was controlled by an increase in soil porosity, and productivity was increased after 4 to 5 years with soil management techniques and incorporation of crop residues. Because of the significance of

Sclerotinia in bean, peanut, and lettuce crops, the corroboration of the hypotheses for its control is quite important.

The results and discussion presented here indicate that the application of EM and green manure increase soil aggregation; reduce compaction; and increase soil porosity, water infiltration, available water and rooting depth. As a result, irrigation frequency and erosion declined, and the soil became suppressive to *S. sclerotiorum*.

The hypothesis that EM microorganisms utilized the external carbon and energy sources to such an extent that it caused a concommitant reduction in the formation of apothecia of *S. sclerotiorum* and in the germination and penetration of ascospores that infect the plants requires corroboration.

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