Application of EM Technology for Intensive Organic Recycling, Soil Quality, Crop Yield and Quality, and Environmental Protection

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Abstract. *A cooperative research study was conducted by Chinese agricultural institutions and the International Nature Farming Center, Nagano, Japan to evaluate the effect of EM technology on organic recycling, soil quality, crop yield and quality, and environmental protection. In the study, EM was mixed with farmyard manure (FYM) and sometimes with poultry manure and fermented prior to application to soil and crops. Compared with traditional FYM (alone) and chemical fertilizer, the EM+FYM treatments 1) increased total soil microbial biomass; 2) improved certain soil physical properties (i.e decreased soil bulk density) and chemical properties (i.e. increased soil cation exchange capacity); 3) increased soil organic matter content; 4) increased the level and plant availability or macronutrients (N-P-K); and 5) increased crude protein content of harvested corn. The grain yields of wheat and corn from the EM+FYM treatment were consistently 10 percent to 20 percent higher over a three-year period compared with FYM alone and chemical alone.*

Introduction

During the last 50 years, there has been great emphasis worldwide to increase agricultural productivity (both land and labour) through increased inputs of fossil fuel energy (largely petroleum products) in the form of machinery, transportation, packaging, irrigation, chemical fertilizers and pesticides (Yuan, 1993). This has been the basic model in transforming traditional agriculture into modern agriculture and the rapid development of agricultural production system, worldwide. At first, the results were dramatic with sharp increases in crop yield and the supply and availability of food. However, with time it became apparent that this new modern agriculture was beset with problems. Intensive production of food crops soon required increasing amounts of chemical fertilizers indicating a progressive decline in fertilizer use efficiency by crops. For example, it was reported that 20 years ago the application of 1 kg of fertilizer nitrogen would increase grain yields by 20 kg, but today 1 kg of fertilizer nitrogen only produces about 10 kg of grain (Fukura, 1985). Intensive production of row crops has led to excessive soil erosion and pollution of groundwater and surface water by plant nutrients, especially nitrate (Ren, 1985). The resulting decline in soil productivity and crop yield and quality, as well as increased environmental degradation, has demonstrated that agricultural production systems that are heavily dependent on "petroleum energy" are unlikely to be sustainable.

Traditional agriculture, though crop yields were low, was largely sustainable because farmers regularly applied organic wastes and residues (i.e. crop residues, animal wastes, green manures and composts) as source of plant nutrients, and to maintain soil tilth and productivity, and to conserve soil moisture. Unfortunately, in their conversion to modern agriculture and heavy use of chemical fertilizers for plant nutrients, organic recycling was often neglected or abandoned entirely.

China is a large agricultural country that produces a vast array of organic wastes that are suitable for soil conditioners and biofertilizers. The predominant waste materials include animal and poultry manures and crop residuess. Unfortunately, they are often not utilized on agricultural lands, and become sources of pollution to the urban and rural environments (Yun, 1993). There is no question that if such wastes were properly and regularly applied to farmland, it would substantially increase the sustainability of modern agricultural systems and minimize their pollution potential to society.

Thus, in view of this situation, it was decided to conduct a study to determine whether EM technology could facilitate the recycling of organic wastes to improve soil quality, crop yield and quality and environmental protection. Another goal was to see if EM technology could enhance the release and availability of waste nutrients to crops so that farmers might reduce their use and application of chemical fertilizers. The study site was a saline soil in the Quzhou Xian of Hebei Province, selected to determine if EM technology could improve the productivity of this problem soil. The study also provided an opportunity to evaluate EM technology on a large scale (Li and Ni, 1995).

Materials and Methods

Raw organic wastes mainly crop residues, straw and animal manures were screened and thoroughly mixed. A portion of the mixture was heaped and fermented to produce traditional FYM, while an equal portion was mixed with EM, heaped and fermented into a product known as EM farmyard manure (EM+FYM).

The experiment was initiated at a site in Quzhou Xian, Hebei Province in June 1993 on a saline soil with an organic matter content of 1 percent (0-20 cm depth), and a total N and P content of 0.07 percent and 0.06 percent respectively (Xin, 1995). Two crops were grown each year, i.e., winter wheat and summer corn. The following treatments were applied to the soil each year.

1) EM farmyard manure (30 t/hm^2)
2) Traditional; farmyard manure (30/hm^2)
2) EM farmyard manure (15/hm^2)
3) Traditional farmyard manure (15/hm^2)
4) Chemical fertilizer (N,P);
5) EM (only)

The prepared organic materials were applied each year in single applications. Chemical fertilizer was applied according to local recommendations in two applications at total rates of 1.125 t/hm^{2}of ammonium carbonate; 0.45 t/hm^2 of urea; and 1.125 t/hm^2 of calcium superphosphate. The macronutrient levels supplied each year from treatments applied to designated plots are shown in Table 1 according to the methods of Hu and Yu (1987). The field experiment was conducted using a randomized block design with four replications and a plot size of 10.5 x 3 m^2. Crops and soils were managed according to local methods and traditions. The EM only plots were sprayed with 0.2 percent EM solution three times during the growth period of each crop.

The total volume of EM solution applied was 15 l/hm^2; at each EM application. Plots without EM treatment were sprayed with equal volume of water.

Table 1. Content of N, P_2O_5 and K_2O in Treatments (kg hm^2)

Treatment No.	N	P_2O_5	K_2O
1	453.0	321.4	286.8
2	453.0	321.4	286.8
3	226.5	160.7	143.4
4	226.5	160.7	143.4
5	516.0	180.0	--
6	--	--	--

In late September 1996 soil samples (cores) (0-20 cm depth) from replicate plots of each treatment of the experiments and composite samples were prepared for determination of the total soil microbial biomass by the chloroform method. In early October 1996 soil sample (cores) were taken from replicate plots of each treatment to depths of 0-20 cm and 20-40 cm and composite samples were air-dried, ground and screened (100 mesh) for analysis of the soil physico-chemical properties according to the following methods (Li, 1983):

Test Item	Test Methods
Soil Volume weight	Ring cutting method
Soil cation exchange capacity	IN NH_4OAC
Soil organic matter	Potassium dichromate volume methods-external heating method
Soil shole N	Semimicro Kjeldahl method
Soil alkaline hydrolysis nitrogen	Alkaline hydrolysis diffusion method
Soil whole P	Acid hydrolysis Mo-Sb anticolorimetric method $HCIO_4$- H_2SO_4 hydrolysis
Soil rapidly available P	Mo-SB anticolorimetric method
Soil rapidly available K	In $NaNO_3$ extraneous turbidimetric method
Soil pH value	pH meter method

Harvested corn samples were collected from both experiments in the summer of 1996. Corn kernels were airdried (off-type and immature kernels were discarded), ground and screened (40 mesh) and the effect of treatments on crop quality parameters was determined including crude protein (percent) by the boiling solution acid N exchange method and crude fat (percent) by the remainder method.

Results and Discussion

Soil Microbial Biomass

The effect of EM, farmyard manure and chemical fertilizer on the total soil microbial biomass is reported in Table 2. The largest microbial biomass was for EM+FYM (30 t/hm^2) and EM (only) which were significantly greater than all other treatments. Treatments which received EM had a higher microbial biomass level than chemical fertilizer and the low rate of FYM. Thus, it is readily apparent that EM provides an initially high inoculum density of microorganisms to the FYM treatment materials. Moreover, with the exception of photosynthetic bacteria, most of the EM cultures (lactic acid bacteria, yeasts, actinomycetes and fungi) are heterotrophic, i.e. they require organic carbon and nitrogen source for their growth and metabolism. This would provide an abundance of proper and available carbon and nitrogen sources. Moreover, the higher FYM rate likely allowed a greater measure of protection and survival of EM cultures from harmful indigenous microorganisms, adverse temperatures and desiccation, all of which could tend to reduce the populations and biomass of EM cultures.

Table 2. Determination of the Soil Microbial Total Amount in the Experiment (mg/100g soil)

Treatment No.	1	2	3	4	5	6
Total Amount of Living Things	70.66aA	56.37bB	54.37bcBC	46.90cC	45.39cC	67.78dD

Soil Bulk Density and Cation Exchange Capacity

The effect of EM, FYM, and chemical fertilizer on the bulk density and cation exchange capacity is reported in Table 3. Bulk density is a measure of the mass of dry soil per unit bulk volume and is an indication of the degree of tightness or compactness of a soil. It also is an indication of whether a soil has a well-developed structure, adequate organic matter, and aeration capacity.

Table 3. The Influence of EM to the Soil Volume Weight and Soil Cation Exchange Capacity

Treated No.		1	2	3	4	5	6
Volume Weight	0-20 cm	1.511eE	1.706cC	1.608dD	1.761aA	1.89cC	1.73bB
	20-40 cm	1.608dD	1.793bB	1.717cC	1.873aA	1.881aA	1.863aA
Cation Exchange Capacity	0-20 cm	10.887aA	9.945cB	10.232bB	9.388dc	9.316dc	9.18eD
	20-40 cm	10.542aA	9.565cC	10.018bB	9.259dD	8.975dD	8.695eE

(Note: Volume weight unit :g/cm^3, cation exchange capacity unit :mg/100g, the following just the same.)

Highly productive agricultural soils generally have bulk densities of less than 1.4 g cm^{-3}. The lowest soil bulk densities in the experiment occurred at 0.20 cm and 20-40 cm where the soil was treated with EM and 30 t/hm^2 of either FYM and poultry manure. Lower bulk densities resulted from the EM+FYM (15 t/hm^2) compared with chemical fertilizer and EM (only).

The data indicate that this saline soil had a residual bulk density of 1.80 to 1.85 g/cm^{-3} at the 0-20 cm depth that could be lowered to a favourable range of 1.50 to 1.55 g/cm^{-3} after treatment with both EM and the high rate of FYM. Chemical fertilizer and EM alone had little effect on bulk density which reflects the absolute importance of applying organic material to lower the soil bulk density and ameliorate its adverse effects on plant quality and yield. It should also be noted that in the experiments the bulk density at the 20-40 cm depth was significantly lowered from 1.85 g/ cm^{-3} (chemical fertilizer and EM alone) to a much more favourable soil bulk density ranging from 1.60 to 1.65 g/cm^{-3} after treatment with EM and both rates of FYM.

The soil cation exchange capacity (CEC) is an important electrochemical property that serves to retain plant nutrient cations in an available form for exchange and uptake by plants. CEC is a very reliable index of soil fertility. The results reported in Table 3 show that EM in combination with both rates of FYM manure caused a significant increase in the CEC at the 0-20 cm depth over that of chemical fertilizer. Similar increases in CEC at the 20-40 cm depth resulted from EM+FYM (30 t/hm^2 and 15 t/hm^2) compared with the CEC value for chemical fertilizer alone. EM alone had little effect on soil CEC at either depth which is indicative of the vital role that organic amendments play in increasing the soil CEC.

Soil Organic Matter Content

The effect of EM, FYM and chemical fertilizer on the soil organic matter content at depth of 0-20 and 20-40 cm is shown in Table 4. The proper and regular addition of organic amendments (i.e. FYM, green manure, crop residues and composted rural and municipal wastes) to soil is probably the single most important management practice that farmers can perform to maintain and improve the tilth, fertility, productivity and health of their soils. Maintenance of the soil organic matter content is vital to achieving long-term agricultural sustainability.

Table 4. The Influence of EM to the Content of the Soil Organic Matter (percent)

Treatment No.	1	2	3	4	5	6
0-20cm	1.307aA	1.141cC	1.243bB	1.093dD	1,064dC	0.999eC
20-40cm	0,661aA	0.571cC	0.629bB	0.562cD	0.535dE	0.572eE

The results presented in Table 4 show that the soil organic matter content increased significantly at the 0-20 and 20-40 cm depths from application of EM+FYM (30 t/hm^2) and was significantly higher than from either the chemical fertilizer treatment or EM alone, neither of which would contribute very much residual organic matter during the course of the experiment. The other combination treatments of EM+FYM also elicited significant increase in the soil organic matter content, compared with FYM alone. This strongly indicates that EM cultures increased the soil microbial biomass because of readily available organic carbon and nitrogen compounds in FYM thereby stabilizing much of the applied organic matter against further decomposition.

Rapidly Available Nitrogen, Phosphorus, and Potassium

The effect of EM, FYM, poultry manure, and chemical fertilizer on the plant available nitrogen, phosphorus and potassium content of soil at depths of 0-20 and 20-40 cm in the experiment is shown in Table 5. The highest residual levels of plant available N, P and K at both soil depth occurred from the EM+FYM (30 t/hm^2) treatments. High residual levels of these nutrients were found N-P-K value for chemical fertilizer was low, not surprisingly, because the soil sampling by that crop. Low residual N-P-K values are also shown for EM (only) in experiments which also is not surprising because EM provides no nutrients directly. (see Table 1).

The data in Table 5 clearly show that both rates of FYM provided a large total amount of N-P-K only part of which was utilized by the fast growing crop. It is also apparent that the growth and activity of EM cultures were effective in mineralizing the organic amendments, thereby releasing N-P-K from their organic configuration and complexes into inorganic plant available forms. Determination of plant-available N-P-K 1 to 2 weeks afer treatment application, but prior to planting, would have provided more meaningful comparisons.

Table 5. The Influence of EM to the Content of Soil Alkaline Hydrolysis, N Rapidly Available P and K (ppm)

Treatment		1	2	3	4	5	6
Content of Alkaline Hydrolysis N	0-20cm	79.597aA	66.775bB	69.605aB	60.745cCD	58.937cD	57.871cD
	20-40cm	39.916aA	35.266bBC	36.902bBA	31.301cDC	29.916dcD	29.981dD
Content of Rapidly Available P	0-20cm	42.912aA	36.309bB	35.285bB	29.427cC	27.3dcDC	26.126dD
	20-40cm	14.891aA	12.961bBA	13.141bBA	11.22cBC	10.414ddC	9.461dD
Content of Rapidly Available K	0-20cm	95.74aA	86.3bB	88.77bB	78.767cC	75.933cC	65.3dD
	20-40cm	74.37aA	65.6abB	67.1bB	58.27cC	55.63	53.13eD

Grain Yield of Wheat (1994-1998) and Corn (1995-1998)

The effect of EM, FYM and chemical fertilizer on the grain yield of winter wheat and summer corn during three cropping years (1994-98) is reported in Table 6. The highest winter wheat yields were obtained with EM+FYM (30 t/hm^2) which produced yields that were 10.4 percent, 12.6 percent and 7.4 percent higher than FYM (30 t/hm^2) in cropping years 1994, 1995 and 1996 respectively. One can assume that EM was responsible for much of this yield increase, possible due to increased availability of plant nutrients or direct beneficial effects on plant growth, health and protection. EM+FYM (15 t/hm^2) produced wheat grain yields that were 10.9 percent, 6.0 percent and 9.7 percent higher than FYM (15 t/hm^2) in 1994, 1995 and 1996 respectively. Again, these results showed the beneficial effect of EM at a lower rate of FYM. Wheat grain yields for EM+FYM (30 t/hm^2) were 18.6 percent, 13.1 percent and 19.9 percent higher than for chemical fertilizer in 1994, 1995 and 1996 respectively, while yields for EM+FYM (15 t/hm^2) were 4.1 percent, 24.2 percent and 12.2 percent higher than chemical fertilizer for these same years, respectively.

Table 6. Analysis of the Influence of EM on the Crop Yield and its Result (kg/hm^2)

Year	Crop	1	2	3	4	5	6
1994	Wheat	3063.6	2739.8	2479.5	2235.0	2581.1	1984.2
1995	Wheat	6035.2	5362.2	5530.4	5219.3	4451.0	3336.7
	Corn	7442.4	6746.9	6474.5	5839.5	6196.8	5199.6
	Total	13477.6	12109.1	12004.9	11058.8	10647.9	8536.3
1996	Wheat	6202.1	5645.3	5803.4	5292.3	5174.1	4033.4
	Corn	6004.5	5347.5	5131.5	4474.5	4362.0	3404.7
	Total	12206.6	10992.8	10934.9	9766.8	9536.1	7438.1
1997	Wheat	7641.0	7305.0	7249.5	6873.0	6162.0	4027.5
	Corn	8257.5	7657.5	7213.5	6907.5	5323.5	5077.5
	Total	15898.5	14962.5	14418.0	13780.5	11485.5	9105.0
1998	Wheat	7065.0	6817.5	6214.5	5850.0	5272.5	4242.0
	Corn	9765.0	9712.5	8797.5	8737.5	8062.5	7485.0
	Total	16830.0	16530.0	15027.0	14587.5	13485.0	11727.0

Note : Winter Wheat variety 1993 early-maturity variety 87-1, 1994 high-yiielding variety 87-5, 1995, 87-5; Summer corn variety was Nongda 60, in 1996 Summer corn variety was Yedan 13.

EM had similar effects on the grain yields of summer corn. Grain yields from EM+FYM (30 t/hm^2) were 10.3 percent and 12.3 percent higher than FYM (30 t/hm^2) in 1995 and 1996, respectively. Yields were higher for EM+FYM (30 t/hm^2) than for all other treatments. Grain yields from EM+FYM (15 t/hm^2) were 10.9 percent and 14.7 percent higher than FYM (15 t/hm^2) in 1995 and 1996 respectively. EM+FYM(30 t/hm^2) produced yields that were 20 percent and 37.6 percent higher than from chemical fertilizer in 1995 and 1996, respectively, while yields from EM+FYM(15 t/hm^2) were 4.5 percent and 17.6 percent higher than from chemical fertilizer in these same years.

Analysis of Yield Component Factors

The effect of EM, FYM and chemical fertilizer on the yield factors of summer corn is reported in Table 7. Grain yield for these crops is largely a composite of the performance and interaction of yield factors, i.e. the product of a) number of ears per mu, b) number of kernels per spike, and c) weight per 1000 kernel. The data indicate that the differences among treatments, especially for EM+FYM and EM+ poultry manure compared with traditional FYM and poultry manure were not great in regard to the first two yield factors, I,e, ears per mu and kernels per spike. Thus, it appeared that EM does not greatly affect these components, at least not under the experimental conditions of this study. However, EM does appear to have had considerable influence on the 1000 – kernel-weight where the EM treatments, excluding EM(only), had higher weights for 1000 kernels than the other treatments.

Table 7. Experiment 1 Analysis of the Yield Factor of Summer Corn in 1995

Treatment No.	1	2	3	4	5	6
Ear Number per mu	3360	3440	3540	3340	3260	3380
Kernel Number per spike	433	23	382	372	382	337
Thousand Kernel Weight	340.9	319.0	329.4	305.9	312.1	309.5

Product Quality of Harvested Corn

The effect of EM, FYM and chemical fertilizer on the crude protein and crude fat content of harvested corn is reported in Table 8. The highest levels of crude protein for harvested corn in experiment were attained with the EM+FYM (30 t/hm^2) and EM+FYM (15 t/hm^2) treatments indicating that EM had improved the quality of FYM, released plant-available nutrients and enhanced its beneficial effects on crop yield and quality. Also, EM only resulted in a high level of crude protein in corn indicating a direct beneficial effect on plant growth and yield. The crude fat content was highest for EM+FYM and EM+ poultry manure at both rates of manure application.

Table 8. The Influence of EM on the Content of Corn Crude Protein and Fat (percent)

Treatment No.	1	2	3	4	5	6
Content of Crude Protein	9.87	8.84	9.37	8.46	7.21	9.08
Content of Crude Fat	4.88	4.32	4.24	3.82	3.77	3.92

Conclusions

- EM combined with FYM and poultry manure, fermented, and applied to soil was shown to significantly increase the soil microbial biomass, decrease the soil bulk density, increase the soil cation exchange capacity, increase the content of soil organic matter, and increase the plant-availability of N-P-K (Li and Wu, 1998).

- The experiments show that EM must be applied with good quality organic matter (i.e. FYM) to achieve maximum beneficial effects. EM cultures mostly require organic carbon and nitrogen compounds for their growth and metabolism. In the process they release inorganic, plant-available nutrients.

- The results showed that the grain yields of winter wheat and summer corn from the EM+FYM treatments were consistently 10 percent to 20 percent higher over a three year period compared with FYM alone and chemical fertilizer alone. The application of FYM, particularly at rated of 30 t/hm^2/year supplies considerable potassium to soil. However, most soils in North China are not limiting in their K content, a situation that could change with intensive cropping (Xin and Li, 1990).

- EM applied with FYM was seen to enhance the quality of harvested corn by increasing the content of crude protein and crude fat.

- Research showed that EM applied with FYM increased the plant-availability of N-P-K in soil (Xin and Li, 1990; Li and Wu, 1998; Yu and Yuan, 1998). The increased growth and activity of EM cultures increases the mineralization and release of inorganic N from organic N compounds (Xin, 1995). Because 1) EM cultures enhance the transformation of $NH4^+$ to $NO3^-$, thereby reducing N volatilization losses (Li, 1998) and 2) photosynthetic bacteria introduced with EM can fix atmospheric N (Kang, 1988).

- The effects of applied EM and their residual effects in the soil-plant ecosystem depends on the soil environmental and ecological conditions that prevail at the time including temperature, moisture, humidity and soil chemical and physical properties. It is most important to realize that most of the microorganisms in EM cultures are heterotrophic and require organic carbon and nitrogen compounds for their growth, nutrition and nitrogen compounds for their growth, nutrition and nitrogen compounds for their growth, nutrition and metabolism. This is why it is important to apply good quality organic amendments in construction with EM applications to soil.

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