Root Dynamics and Nutrient Uptake Efficiencies of Mung Bean as Affected by Organic Matter and Effective Microorganisms

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Abstract

Organic farming systems are evolving rapidly in all parts of the world, to meet the demand for pollutant free food for humankind. Furthermore, these systems have been identified as alternative and sustainable units to maintain productivity in contrast to current chemical food systems. However, due to lower concentrations of nutrients available in organic manures and the requirement of very large quantities of these materials, nutrient use efficiencies of crops play a deterministic role in maintaining productivity of organic farming systems.

Effective Microorganims (EM) is proven to increase productivity of organic farming systems in all climatic zones. However, the mechanisms of action of EM are not well defined. Thus field studies were undertaken to evaluate the role of EM on selected soil properties and root development patterns of a selected legume, mungbean, over two seasons, along with nutrient uptake efficiencies when grown in different organic systems.

Application of organic manures enhanced water holding capacities and reduced bulk densities of soil. Application of EM enhanced these processes. Thus the root growth of mungbean was enhanced, resulting in greater branching, especially in terms of secondary and tertiary branches, which are responsible for nutrient and water uptake. Furthrmore, nodulation was also increased by the application of EM, due to the presence of more sites of inoculation. The utilization efficiencies of applied and soil nitrogen and potassium were also increased by EM. The impact of the microbial solution was greater when supplied with organic matter with a low C:N ratio. The resultant effect was greater yields of mungbean, which was significantly correlated with nutrient uptake efficiencies.

Introduction

Organic farming systems are being established in all parts of the world due to their ability to produce pollutant free food for humankind (Pretty, 1996). The absence of hazardous agrochemicals in these farming units make the products acceptable to consumers. The value of these farming systems are further enhanced by their ability to produce acceptable yields on a sustainable basis (Beets, 1990, Blobaum, 1995), unlike the conventional units using agrochemicals. This is attributed to the ability of organic matter to enhance soil quality unlike agrochemicals (Wade and Sanchez, 1983). Thus these farming systems are widely acclaimed as vital elements in the future agricultural programmes, especially in the developing countries (IFIA, 1992). A limitation often cited in organic farming systems is low yields when compared to conventional systems. This is related to the relatively low concentration of nutrients in organic mater commonly used in most developing nations. The slow release of nutrients, lower decomposition rates due to the high C:N ratios, poor nutrient balances and loss of nutrients are also reasons attributed to the low productivity of most organic farms (Corsico, 1985, Lockeretz, 1988).

Research in the recent past has concentrated on methods of enhancing the productivity of organic farming systems. Among the many techniques developed, the use of microbial inoculants has obtained much prominence due to the ability of these organisms to release the bound nutrients in most organic matter at required times for crop utilization (Parr et al, 1994). A technique using this concept that has gathered momentum in many countries is that of Effective Microorganisms (EM) (Higa, 1991, 1994). The solution of EM, which contains naturally occurring microbes enhance the utility value of organic matter. Thus many research programmes from different parts of the world (e.g. Parr et al, 1997), highlight the benefits of this microbial solution to enhance and maintain crop productivity.

The beneficial effect of EM on crop productivity is attributed to many factors. These include greater vigour of plants, improvement of soil properties, rapid decomposition of organic matter and greater uptake of nutrients (Higa, 1994). However, yields of crop plants are directly affected by root growth (Gregory, 1996), as these provide the plant with nutrients and water for photosynthesis. The impact of EM in promoting root growth of crops has not been identified and the reported vigour of crops grown with EM could be associated with this factor. Thus, a field study was undertaken over two seasons to determine the impact of EM on soil properties, root growth and nutrient uptake efficiencies of mungbean (*Vigna radiata L.* Wilczek) when applied with organic matter. The yields of the crop as affected by these parameters was also determined in both seasons.

Methodology

The experiments, which are a part of an ongoing research programme were conducted at the experimental station of the Unversity of Peradeniya, Sri Lanka (8° N, 89°E, 421 m above sea level) in the mid country intermediate zone of Sri Lanka, over the years 1994 and 1995. The soil of the site was an Ultisol (Rhododult) with a pH (1:2.5 H_2O) of 6.41 $\pm$ 0.17 and a organic matter content of 0.78 percent $\pm$ 0.04 percent. The bulk density of the soil 1.72 g/cm^3 with a water holding capacity of 19.54 percent. The mean climatic parameters of the site over the period of study were – rainfall 1143 mm, mean monthly temperature of 26.3°C $\pm$ 3.21 °C and a relative humidity of 76.3 percent $\pm$ 3.58 percent.

The crop selected for the study was mungbean *Vigna radiata L.* Wilczek – variety MI 5), a popular food legume of this region. The treatments imposed were those of the continuing ling term experiment. Thus 3 organic materials, namely coir dust, a mixture (1:1) of fresh leaves of *Gliricidia* and *Leucaena* (tree legumes) and rice straw were applied to plots (3 x 4m) that had received these materials for the last two years, with or without EM. Control plots to which no organic matter was added were also maintained with and without EM in both seasons.

The organic matter was incorporated to the plots at a rate equivalent to 10 mt per ha (1 kg of fresh material per sq. m) two weeks before planting. The EM solution diluted 1:500 times was sprayed onto the selected plots at the time of adding organic matter. The rate of EM applied was equivalent to 5 *l* per ha. The microbial solution was also sprayed onto the leaves of the growing crop at a dilution of 1:1000 (rate of 4 *l* per ha), at V4 and R4 growth stages in both seasons. Thus the experiment which had 8 treatments was conducted as a factorial trial within a randomized block design with 3 replicates. Adequate precautions were taken to ensure the absence of cross contamination of the EM treated and untreated plots.

With the onset of rains in each season, the organic matter was incorporated into the plots. No agrochemicals were added and the crop was planted at a spacing of 10 x 20 cm. The crop was managed as per recommendation of the Department of Agriculture (1989). Hand weeding was carried out on two occasions, while complimentary irrigation was provided.

At the onset and end of each experiment, the bulk densities and organic matter contents of the soil of the experimental plots (0-30 cm depth) were determined by methods described by Black (1965). At the R1 growth stage, 5 plants of mungbean were carefully uprooted and the root morphology analyzed as per method described by Fitter (1982). Thereafter, the plants were dried at 80° C to a constant weight and nitrogen and potassium contents analyzed by Kjeldhal and Flame photometric methods respectively. At crop maturity, seed yields per plant were determined.

The nitrogen and potassium contents of plants (mg nutrient in 100 mg dry mater) were utilized to determine the Nutrient Uptake Efficiency (NUE) using the difference method described by Rao et al (1992). The NUE values of nitrogen and potassium (N/K) were determined in relation to the bare soil (A), in relation to the soil supplied with EM (B) and in relation to organic matter applied (C), using the following equations.

$$\text{NUE in relation to soil (A)} = \frac{\text{N/K in plant grown with OM} - \text{N/K in plant grown on soil}}{\text{Quantity of added nutrient}}$$

NUE in relation to soil with EM (B) =

$$\frac{\text{N/K in plant grown with OM + EM – N/K in plant grown on soil with EM}}{\text{Quantity of added nutrient}}$$

NUE in relation to added OM (C) =

$$\frac{\text{N/K in plant grown with OM + EM – N/K in plant grown with OM}}{\text{Quantity of added nutrient}}$$

The data of the two seasons were subjected to appropriate statistical analyses to determine the significance of treatment differences.

Results and Discussion

The chemical characteristics of the organic materials used illustrate a high nitrogen content in legume leaves (Table 1). In contrast, coir dust and straw had high C:N ratios and a comparatively greater concentration of potassium.

Cultivation of crops on bare soil over the two seasons had no effect on bulk density (Table 2). However, at the end of the second season the water holding capacity of the soil of these plots was reduced. This showed the adverse impact of continued cultivation of soil without additions of nutrients or amendments.

Table 1. Selected Chemical Properties of Organic Matter

Material	% Nitrogen	% Phosphorus	% Potassium	C:N Ratio
Coir dust	0.76±0.04	0.14±0.01	3.24±0.14	49.5±2.15
Legume leaves	3.46±0.17	0.15±0.02	0.65±0.02	12.6±1.27
Rice straw	0.71±0.03	0.07±0.01	2.99±0.27	53.5±4.08

Table 2. Effect of EM and Organic Matter on Selected Physical Properties of Soils

Treatment		Bulk Density (g/cm3)		Water Holding Capacity (% oven dried soil)	
		Season 1	**Season 2**	**Season 1**	**Season 2**
Bare soil	No EM	1.65	1.61	20.65	19.58
	With EM	1.64	1.61	21.94	21.99
Legume leaves					
	No EM	1.58	1.54	21.84	22.42
	With EM	1.53	1.49	22.89	23.64
Rice straw					
	No EM	1.56	1.52	22.42	23.04
	With EM	1.51	1.48	23.24	23.89
Coir dust					
	No EM	1.51	1.49	24.25	25.14
	With EM	1.47	1.44	25.96	26.99
Probability					
	Organic matter	0.044	0.047	0.024	0.039
	EM	0.038	0.029	0.034	0.019
	Interaction	0.058	0.298	0.268	0.458

The application of organic matter reduced bulk densities and enhanced water holding capacities. The impact was greater when organic matter with a high C:N ration was applied, due to their lower decomposition rates, Thus the benefits of organic matter in improving soil properties was illustrated, confirming earlier reports (e.g. Marschner, 1995). Application of EM enhanced the benefits of organic matter application. The bulk densities were reduced, while water holding capacities were increased, in some instances significantly. The significant interaction between organic matter and EM also showed that the effect of the microbial solution was different with each organic manure. This could be due to the variations in C:N ratios of the manures as the microbial solution tends to decompose organic matter with a high nitrogen content at a faster rate (Higa, 1991). The increase in water holding capacity is therefore lower in soils supplied with legume leaves and EM when compared to that of soil to which coir dust was added with EM. The C:N ratio and EM reduced this parameter to a greater extent.

The root number of mungbean plants grown in the dry season was greater (Table 3). This is due to the greater response of plants to dry conditions when root growth is enhanced to utilize available water in the soil (Gregory 1996). In contrast, application of organic matter reduced root numbers in both seasons. This is due to the ability of organic matter to increase water holding capacities (Table 2), as reported by Mengel and Kirkby (1985). Again, the impact of an organic matter with a higher C:N ratio was greater. Thus the application of legume leaves had the least beneficial impact on root growth of mungbean.

Table 3. Root Branching Patterns of Mungbean as Affected by Organic Matter and EM at R1 Growth Stage in Two Seasons

Treatments	First Order		Second Order		Third Order*	
	S1	**S2**	**S1**	**S2**	**S1**	**S2****
Bare soil						
No EM	37	42	12	16	7	9
With EM	39	45	14	17	10	13
Legume leaves						
No EM	36	45	15	18	9	12
With EM	47	52	19	23	12	18
Rice straw						
No EM	34	40	12	16	12	14
With EM	43	48	18	25	17	20
Coir dust						
No EM	32	38	14	19	10	12
With EM	39	46	19	25	17	21
Probability						
Organic matter	0.045	0.025	0.018	0.043	0.015	0.038
EM	0.019	0.040	0.037	0.024	0.019	0.015
Interaction	0.044	0.024	0.034	0.010	0.019	0.035

* Root order defined as per Fitter, 1992

** S1 and S2 denote wet and dry seasons respectively

Application of EM also enhanced root growth. The lowest impact as when EM was applied onto the bare soil, although the lateral roots (2nd and 3rd order roots) increased significantly. Similarly application of EM to organic matter stimulated the development of the lateral roots to a greater extent than the primary roots. This is best shown by the regression equations (Table 4) between root numbers and types, where the gradients decline with the application of organic matter and EM, especially in the dry season.

Application of EM to the bare soil decreased the gradient of root orders of plants grown without EM by 8 percent and 14 percent in the wet and dry seasons respectively. Application of organic matter alone also reduced gradients significantly, thus implying the greater development of later roots, which are responsible for the uptake of nutrients and water. Similarly, within treatments of supplying the respective organic materials, EM reduced gradients especially in the dry season, thus confirming the benefits of this microbial solution in enhancing root branching.

Application of organic matter increased NUE of mungbean when compared to plants grown on the bare soil (Table 5). The impact of organic matter in enhancing NUE is greater in the dry season which could be related to better root growth observed in this season. This illustrated another advantage of adding organic matter to soils.

A comparison of NUE due to organic mater and EM in relation to the application of EM to soil highlights the benefits of the microbial solution. While the addition of EM to the soil alone is not very effective, and the inclusion of organic matter increases NUE significantly. This is directly related to the decomposition of the organic manures by EM (Higa, 1994), and is seen to be greater in the dry season. Thus, EM is best applied with organic matter to enhance nutrient uptake efficiencies by crops.

Table 4. Regression Equations between Root Order and Root Numbers in Mungbean in Wet and Dry Seasons

Treatments	Seasons 1	Season 2
Bare soil		
No EM	Y = -0.992 (1nx) + 2.425 (r^2 = 0.675)	Y = -0.751 (1nx) + 1.096 (r^2 = 0.641)
With EM	Y = -0.912 (1nx) + 1.964 (r^2 = 0.715)	Y = -0.642 (1nx) + 2.914 (r^2 = 0.599)
Legume leaves		
No EM	Y = -0.714 (1nx) + 3.144 (r^2 = 0.704)	Y = -0.688 (1nx) + 0.954 (r^2 = 0.811)
With EM	Y = -0.594 (1nx) + 2.058 (r^2 = 0.801)	Y = -0.449 (1nx) + 1.947 (r^2 = 0.647)
Rice straw		
No EM	Y = -0.684 (1nx) + 1.028 (r^2 = 0.711)	Y = -0.592 (1nx) + 1.801 (r^2 = 0.586)
With EM	Y = -0.515 (1nx) + 2.045 (r^2 = 0.884)	Y = -0.402 (1nx) + 2.028 (r^2 = 0.901)
Coir dust		
No EM	Y = -0.584 (1nx) + 2.754 (r^2 = 0.810)	Y = -0.511 (1nx) + 1.989 (r^2 = 0.795)
With EM	Y = -0.424 (1nx) + 3.011 (r^2 = 0.709)	Y = -0.354 (1nx) + 3.045 (r^2 = 0.864)

Table 5. Nitrogen and Potassium Uptake Efficiency of Mungbean as Affected by Organic Matter and EM in Two Seasons at the R1 Growth Stage

Treatments		Nitrogen			Potassium		
		Uptake Efficiency (%)					
Season 1		A*	B**	C***	A*	B**	C***
Bare soil	No EM	-	-	-	-	-	-
	With EM	-	-	-	-	-	-
Legume leaves	No EM	21.2	-	-	25.5	-	-
	With EM	-	23.6	27.1	-	31.4	25.8
Rice Straw	No EM	24.7	-	-	29.5	-	-
	With EM	-	34.8	21.6	-	41.4	19.5
Coir dust	No EM	26.9	-	-	31.5	-	-
	With EM	-	45.2	18.7	-	49.8	14.2
Season 2		A	B	C	A	B	C
Bare soil	No EM	-	-	-	-	-	-
	With EM	-	-	-	-	-	-
Legume leaves	No EM	26.5	-	-	29.8	-	-
	With EM	-	32.5	31.5	-	35.8	36.0
Rice Straw	No EM	30.4	-	-	34.3	-	-
	With EM	-	40.5	27.9	-	42.7	30.4
Coir dust	No EM	26.9	-	-	31.5	-	-
	With EM	-	48.3	25.4	-	49.8	22.1

* A is NUE due to EM in relation to bare soil ** B is NUE of OM and EM in relation to soil without EM.
*** C is NUE due to organic matter (OM) + EM in relation to OM alone

The benefits of the microbial solution to organic farming in terms of making greater quantities of nutrients available through better and faster decomposition is best illustrated by the NUE's obtained from plants grown with and without EM (Table 5). Application of EM to organic matter enhanced NUE significantly. A greater impact is observed in terms of nutrients present in lower concentrations in the organic matter. Thus the NUE of potassium is greater in plants grown with EM and legume leaves which has a lower concentration of this element than rice straw or coir dust. Similarly the NUE of nitrogen is greater when EM is added to straw or coir dust. This presents a very interesting phenomenon where EM facilitates the availability of a nutrient present in low concentrations for plant growth. The greater impact of EM in increasing NUE's in the dry season was also observed. This could be associated with the enhanced growth of 2nd and 3rd order roots of plants to which EM is applied in this season (Table 2).
The benefits of organic matter and EM in terms of practical value is best shown by yields (Table 6). Application of organic matter alone increased yields of mungbean in both seasons. The most significant impact is observed with organic matter with a low C:N ratio. This clearly indicated the beneficial impact of using organic matter with low C:N ratios in organic matter such as coir dust, especially in the dry season, when compared to growing plants without any additives.
In the wet and dry seasons, application of EM to bare soil increased yields by 6 percent and 9 percent respectively. Application of EM to legume leaves enhanced yields by 14 percent and 17 percent in the wet and dry seasons. In contrast, the impact of EM with coir dust and rice straw was lower in both seasons (8–12 percent), which could be due to the lower nutritive value and high C:N ratio of these materials.

Table 6. Effect of Organic Matter and EM on Yields of Mungbean in Wet and Dry Seasons

Treatment		**Seed Yield (g/m^2)**	
		Season 1	**Season 2**
Bare soil	No EM	128	95
	With EM	136	104
Legume leaves	No EM	246	182
	With EM	281	214
Rice straw	No EM	185	140
	With EM	204	158
Coir dust	No EM	168	150
	With EM	182	165
Probability			
	Organic matter	0.018	0.035
	EM	0.042	0.024
	Interaction	0.186	0.381

Conclusions

This study, which is one in a series illustrate the practical benefits of using the microbial solution in organic farming. The impact is greater in the dry season, when the environment is less conducive to crop production, which often results in yield losses. These benefits could be associated with the enrichment of soil properties, root growth and NUE's as observed in this study. The study also illustrated that the efficacy of the microbial solution could vary with the type of organic matter used in tropical farming systems.

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References

Beets, W.C. 1990. Raising and Sustaining Productivity of Smallholder Farming Systems in the tropics. Ag Be Publishers, Holland, 731 pp.

Black, C.A. 1965. Methods of Soil Analysis. Soil Science Association of America, Madison, Wisconsin, USA, 642 pp.

Blobaum, R. 1995. Two years after Rio: Progress in making a global transition to sustainable agriculture. In Sustainable Food Production in the Asian and Pacific Region. Food and Fertilizer Technology Center Book series 46 : 4 – 7.

Corsico, W.C. 1965. Organic Fertilizer – Their Nature, Properties and Use. University of Los Banos, Philippines, 136 pp,

Department of Agriculture 1989. Technoguide to Crop Production. Department of Agriculture, Peradeniya, Sri Lanka, 186 pp.

Fitter, A.H. 1982. Morphometric analysis of root systems – Application of techniques and influence of soil fertility on root system development in two herbaceous species. Plant Cell and Environment 5 : 313 – 322.

Gregory, P.J. 1996. Spatial distribution of root systems and root activities. In Roots and Nitrogen in Cropping Systems of the Semi arid Tropics. Ed. O. Ito et al, JIRCAS, Tsukuba, Japan : 129 – 144.

Higa, T. 1991. Effective Microorganisms : A biotechnology for mankind. In Proceedings of the 1st International Conference on Kyusei Nature Farming. Ed. J.F. Parr et al, USDA, Washington, USA, 6-15.

Higa, T. 1994. Effective Microorganisms : A new dimension for nature farming. In proceedings of the 2nd International Conference on Kyusei Nature Farming. Ed. J.F. Parr et al, USDA, Washington, USA, 20 – 22.

IFIA. 1992. Sustainable agricultural systems for the 21st century – the role of mineral fertilizer. International Fertilizer Industry Association, Paris, France, 16pp.

Lockeretz, W. 1988. Open questions in sustainable agriculture. American Journal of Alternative Agriculture 3 : 174 – 181.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press, London, UK, 889pp.

Mengel, K. and E.A. Kirkby, 1985. Principles of Plant Nutrition. International Potash Institute, Bern Switzerland, 687p.

Parr, J.F., S.B. Hornick and D.D. Baufmann. 1994. Use of microbial inoculants and organic fertilizers in agricultural production. FFTC Extension Bulletin, Food and Fertilizer Technology Center, Taiwan, 16pp.

Parr, J.F., S.B. Hornick and M.E. Simpson. 1997. Proceedings of the 3rd International Kyusei Nature Farming Conference, USDA, Washington, USA, 284pp.

Pretty, J.N. 1996. Regenerating Agriculture. Vikas Publishing House, New Delhi, India, 320pp.

Rao, A.S., J.L. Smith, J.F. Parr and R.I. Papendick. 1992. Considerations in estimating N recovery efficiency by the difference and isotopic dilution methods. Fertilizer Research 33: 209 – 217.

Wade, M.R. and P.A. Sanchez 1983. Mulching and green manure application for continued crop production in the Amazon basin. Agronomy Journal 75 : 39 – 45.