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Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan

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Abstract

A field experiment was conducted to determine the effects of integrated use of organic and inorganic nutrient sources with effective microorganisms on growth and yield of cotton. Treatments included: control; organic materials (OM); effective microorganisms (EM); OM + EM; mineral NPK (170:85:60 kg); 1/2 mineral NPK + EM; 1/2 mineral NPK + OM + EM and mineral NPK + OM + EM. OM and EM alone did not increase the yield and yield attributing components significantly but integrated use of both resulted in a 44% increase over control. Application of NPK in combination with OM and EM resulted in the highest seed cotton yield (2470 kg ha^{-1}). Integrated use of OM + EM with 1/2 mineral NPK yielded 2091 kg ha^{-1}, similar to the yield (2165 kg ha^{-1}) obtained from full recommended NPK, indicating that this combination can substitute for 85 kg N ha^{-1}. Combination of both N sources with EM also increased the concentrations of NPK in plants. Economic analysis suggested the use of 1/2 mineral NPK with EM + OM saves the mineral N fertilizer by almost 50% compared to a system with only mineral NPK application. This study indicated that application of EM increased the efficiency of both organic and mineral nutrient sources but alone was ineffective in increasing yield.

Keywords: Cotton; Effective microorganisms; *Gossypium hirsutum* L.; Mineral fertilizer; Nutrient uptake; Organic materials

1. Introduction

Mineral fertilizers have significant effects on food production in the world, and are an indispensable component of today's agriculture. Estimates show that a 50% increase in agricultural production is brought about through chemical fertilizers (FAO, 1989), and 60% of humanity eventually owes its nutritional survival to nitrogen (N) fertilizers (Fixon and West, 2002). Unfortunately, recovery of N in soil–plant systems seldom exceeds 50% of the applied N, while the remainder is lost (Abbasi et al., 2003). Growing concerns about the environmental consequences of mineral N use and its future cost perspectives emphasize the need to develop new production technologies that are sustainable both economically and ecologically. There are concerted efforts world wide to use green manuring, legumes and organic manures to provide the same amount of food with less fossil fuel based inorganic fertilizers. Increased recycling of plant residues, agro-industrial wastes, municipal wastes and animal manures is likely to complement the N availability and reduce dependence on mineral N fertilizers (Chambers et al., 2000). In addition, use of chemical fertilizers alone does not sustain productivity under

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continuous intensive cropping, whereas inclusion of organic materials improves physical soil properties (Benbi et al., 1998), builds up soil fertility and increases crop yield (Yaduvanshi, 2003).

Organic materials hold great promise due to their local availability as a source of multiple nutrients and ability to improve soil characteristics. According to several authors the improvement of fertility and quality of soil, especially under low input agricultural systems, requires the input of organic materials (Stamatiadis et al., 1999; De Jager et al., 2001; Palm et al., 2001; Ouedraogo et al., 2001; Soumare et al., 2003). In previous studies, addition of farmyard manure with half the recommended mineral N produced wheat yield similar to that produced by the full recommended dose of mineral N (Ahmad et al., 2002) while the nutrient status of soil increased and soil physical conditions improved when *Populus euramericana* leaves were added to soil (Abbasi et al., 2002).

The effect of organic nutrients on crop yield is long term and not immediate, thus, farmers are reluctant to use organic fertilizers in their cropping system. However, use of effective microorganisms (EM) inoculum along with organic/inorganic materials is an effective technique for stimulating supply and release of nutrients from these nutrient sources. Some studies have shown that the inoculation of agro-ecosystems with EM cultures can improve soil and crop quality (Higa and Parr, 1994; Hussain et al., 1999). Similarly, Daly and Stewart (1999) reported that application of EM to onion, pea and sweet corn increased yields by 29%, 31% and 23%, respectively. Higa and Wididana (1991) stated that EM is not a substitute for other management practices but is an additive for optimising all other amendments and practices used for crop production.

Hence, the present experiment was carried out to evaluate the effect of integrated use of organic and mineral fertilizers with effective microorganisms on the yield and nutrient uptake of cotton (*Gossypium hirsutum* L.). The economics were also examined.

2. Methods

2.1. Field study and experimental arrangements

A field experiment was conducted in the research area of the Soil Science Department, University of Agriculture, Faisalabad, Pakistan during the summer (Kharif) season 1999–2000. The surface soil (0–15 cm) of the experimental site had pH 7.65, ECe 1.32 dS m^{-1}, organic matter 4.6 g kg^{-1}, total N 0.41 g kg^{-1}, available P 6.2 mg kg^{-1} and exchangeable K 78.4 mg kg^{-1}. The soil was sandy clay loam and classified as Typic Camborthids belonging to Hafizabad soil series (Soil Survey Staff, 1999). The meteorological data of the experimental site of Faisalabad during the growth period of the crop are given in Table 1. The experiment was a randomised complete block design (RCBD) with three replications. Individual plot size was 16.2 m^2 (3.6 m × 4.5 m). The experiment involved the treatments: T_0: control; T_1: 10 Mg ha^{-1} organic material (OM, dry weight basis), i.e. farmyard manure (FYM) + poultry manure (PM) + sugarcane filter cake (SFC) in the ratio of 4:3:3 (suggested by Higa and Parr, 1994); T_2: extended effective microorganisms (EM), i.e. mixture of basic EM, molasses and water in the ratio of 1:1:20; T_3: OM + EM; T_4: full recommended NPK fertilizer (N 170:P 37:K 50 kg ha^{-1}); T_5: 1/2 recommended NPK fertilizer + EM; T_6: 1/2 recommended NPK fertilizer + OM + EM; T_7: full recommended NPK fertilizer + OM + EM. EM was applied at the rate of 2.5 L ha^{-1} as recommended by Higa and Parr (1994).

Effective microorganisms (EM) was a mixed culture of beneficial microorganisms including a predominant population of lactic acid bacteria (*Lactobacillus* sp.) and yeast (S*accharomyces* sp.), and a small proportion of photosynthetic bacteria (*Rhodopseudomonas* sp.), actinomycetes and fermenting fungi. The EM fermenter was a cemented structure, 6 m long, 3 m wide and 1.5 m deep (from the top of the water channel), having two openings (inlet and outlet of water). It should be constructed near/along the main water channel. The organic wastes (FYM, SFC, PM) were added to a depth of approximately 1 m, and the fermenter was then filled with water and mixed for proper decomposition of organic waste. In the case of EM—super fermenter water irrigation, one half of the irrigation water was passed through the fermenter to which extended EM (one part basic EM + 1 part molasses + 20 parts water by volume, allowed to multiply for 3 days after mixing) was added at least 5 days before every irrigation for fermentation of organic waste. EM solution was brought from the Nature Farming Research Centre, University of Agriculture, Faisalabad, Pakistan. The pH of fermented water was slightly acidic (pH 6).

Table 1
Meteorological data for rainfall (mm), temperature (°C), and relative humidity (%) of the experimental area during the months of May–December, 1999

Months	Rainfall (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
May	110	41.1	25.5	31.6
June	60	40.1	27.5	32.0
July	82	38.5	28.8	44.3
August	74	37.9	27.9	49.5
September	42	38.0	26.4	44.0
October	28	35.1	19.6	44.6
November	18	29.0	13.2	50.8
December	40	24.0	7.7	60.0

The mineral fertilizers urea, diammonium phosphate (DAP) and potassium sulphate were used as sources of nitrogen, phosphorus and potassium, respectively. Half the dose of N and all of the P and K were distributed and incorporated thoroughly into the soil at sowing. The remaining N was applied in two equal doses at the first and second irrigations. Organic materials were incorporated thoroughly into the respective plots four weeks before sowing. The chemical constituents of FYM, SFC and PM were: N 1.43%, 1.37%, 3.50%; P 2.1, 7.8, 8.0 mg g^{-1} and K 6.7, 5.0, 6.9 mg g^{-1}, respectively.

Cotton (cultivar CIM-443) was sown on May 19th 1999 with 0.75 m row to row spacing. After proper germination and establishment, 0.4 m plant to plant spacing (thinning) was maintained. The quantity and interval of cultural practices, plant protection measures and irrigations was the same for all the treatments and was performed according to the general recommended methods. Five to six irrigations (watering) were given to crops during the study. The appropriate combinations of both pre-emergence and post-emergence sprays were applied to control weeds. In addition, major weeding at the time of thinning by hand hoeing and by inter row cultivar was done to destroy the weeds. Bollworm and pink bollworm generally destroy the contents of the boll. The heat treatments of seed were carried out to kill the pink bollworm. Similarly, plants were defoliated with a contact herbicide before picking so that leaves did not foul mechanical pickers. Data on the yield attributes (sympodial branches, open bolls per plant, boll weight) and seed cotton yield were determined. The yield attributes were measured by selecting 10 plants randomly from three central rows while seed cotton yield was determined from the whole plot.

2.2. Chemical analysis

At the blooming stage, 5–6 healthy leaves from each selected plant were collected. The leaves were washed, cleaned, air dried and then oven dried at 65 °C to a constant weight. The samples were ground, sieved and stored in small plastic bags for the determination of total N (Jackson, 1962), and P and K analysis according to Winkleman et al. (1990).

2.3. Economic and statistical analysis

Growth, yield and soil parameters were recorded and then analysed statistically according to standard statistical procedures described by Steel and Torri (1980). The treatment means were compared by Duncan's multiple range test at 5% probability level (Duncan, 1961). For economic analysis, after considering the cost of fertilizer N, P, K, organic materials and EM application, the incomes from seed cotton yield were used for economic analysis (CIMMYT, 1988) using the formula:

$$\text{Net return} = \text{value of increased yield obtained} - \text{cost of mineral/organic/biological nutrient sources}$$

$$\text{Value cost ratio (VCR)} = \text{value of increased yield obtained/cost of mineral/organic/biological nutrient sources}$$

$$\text{Relative increase in income (RII)} = (\text{net income/income at control}) \times 100$$

The incomes in Rupees were converted into US$ based on the prevailing currency rate (year 2004–2005).

3. Results and discussion

3.1. Yield and yield components of cotton

Application of organic materials or EM alone did not increase yield significantly over control (Table 2). However, combination of both resulted in a 44% increase in yield over control. When EM was applied with OM (T_3), a 23% increase in yield was recorded as compared to OM alone (T_1). On the other hand, application of EM with mineral NPK in T_7 resulted in a 14% increase in yield over T_4 (mineral NPK alone). The increase in yield resulting from EM application was low in mineral NPK treatments compared to T_3, showing that EM had more visible and significant effects when applied with organic materials. The relatively low response of mineral NPK to EM was expected because EM is a mixture of different microorganisms (MO) which can respond well only in the presence of sufficient OM. Aryal et al. (2003)

Table 2
Effect of integrated use of organic and mineral nutrient sources with effective microorganisms (EM) on the growth and yield components of cotton

Treatments	Height (cm)	Sympodial branches	No. of balls $plant^{-1}$	Seed cotton weight $boll^{-1}$ (g)	Yield (kg ha^{-1})
T_0	90.3	8.6	24.7	1.10	1076
T_1	92.7	10.0	32.8	1.15	1263
T_2	95.5	11.0	32.4	1.12	1278
T_3	103.2	12.3	43.5	1.17	1552
T_4	109.3	14.2	45.3	1.40	2165
T_5	109.2	13.7	45.1	1.24	1875
T_6	109.7	13.7	45.7	1.32	2091
T_7	110.6	15.2	48.3	1.50	2470
LSD	2.94	1.96	3.78	0.083	208

T_0: control, T_1: OM; T_2: EM; T_3: OM + EM; T_4: NPK; T_5: 1/2 NPK + EM; T_6: 1/2 NPK + OM + EM; T_7: NPK + OM + EM.
LSD represents least significant difference using Duncan's test at the 5% probability level.

reported that application of *Rhizobia* and AM fungal inoculation to bean plants significantly increased pod yield in organic fertilization treatment, but not in chemical fertilization treatment. The performance of organic materials and EM was not as expected when they were applied alone. The native soil OM concentration was very low, just 0.46%, and the release of nutrients from organic sources is generally considered very slow. Therefore, addition of any organic material could not increase production to the same extent as mineral fertilizer. Moreover, added organic materials or mineral fertilizers in soils with low OM could be utilized first by the microbial population (immobilization), and competition always exists between plants and MO for applied N. As plants need more energy for nutrient absorption and uptake, microorganisms become successful initially in utilizing most of the applied N because of the energy factor. Therefore, release of available nutrients from organic materials and their absorption by plants and the re-mineralization of immobilized N require time, which might not be completely possible in just one season.

Addition of N fertilizers increased the growth and yield of cotton significantly ($P \leqslant 0.05$) by 73–130%. The maximum yield (2470 kg ha^{-1}) was recorded in T_7 where OM and EM were mixed with full mineral NPK followed by full recommended mineral NPK treatment (T_4), where 2165 kg ha^{-1} of seed cotton yield was recorded. The combination of OM + EM with 1/2 mineral NPK (T_6) yielded 2091 kg ha^{-1} of cotton seed, very similar to that obtained from full recommended mineral NPK (2165 kg ha^{-1}), and the difference between the two was non-significant. Results indicated that addition of 10 Mg ha^{-1} of organic materials with effective microorganisms could substitute about half of the recommended fertilizer amount (85 kg N), possibly because of the greater amount of N and P supplied to soil. In an intensive rice–wheat cropping system, substitution of up to 60 kg N and 13 kg P ha^{-1} by the application of green manure or FYM has been reported by Yaduvanshi (2003) and in maize 12 t FYM ha^{-1} can substitute for 60 kg N and 13.2 kg P ha^{-1} (Meelu and Singh, 1978).

3.2. NPK contents in plants

Application of organic materials and EM alone or in combination with mineral NPK significantly increased the concentrations of N, P and K in cotton (Table 3). Organic materials alone increased N contents of plants by 16% over control. The N contents of plants increased to 38% when EM was mixed with organic materials, resulting in a 22% increase in N concentration. Effective microorganisms enhance the degradation and chemical breakdown of organic materials and stimulate the process of mineralization of organic matter (Higa and Kinjo, 1991; Hussain et al., 1999), releasing more nutrients into the soil–plant system (Daly and Stewart, 1999). The highest N concentration (40–47%) was recorded where mineral fertilizer was applied as the full recommended amount or 50% mineral NPK with OM and EM. A non-significant difference between these two treatments showed that application of EM or organic materials with half of the N fertilizer increased the recovery and uptake of N equivalent to the full recommended amount of mineral NPK. Ahmad (1994) reported a positive interaction between organic (biological nutrients) and mineral fertilizers, which increased the efficiency of fertilizers and thereby reduced their loss to environment. Similarly, Yaduvanshi (2003) observed a greater N yield in rice and wheat after the combined application of organic manures with mineral fertilizers. Phosphorus and potassium had a similar trend, except that phosphorus was increased significantly even when EM was applied alone. The percent increase of phosphorus over control was 14–27% and 34–35% in the cases of organic and mineral fertilizer application alone or mixed, respectively. Uptake of potassium was relatively higher than N and P, and increase over control ranged from 10% in organic material to a maximum of 59% in NPK fertilizer + OM + EM. The increase in K may partly be attributed to the concentration effect (Troeh and Thompson, 1993) which does not have any risk of loss in soil.

Table 3
Effect of integrated use of organic and mineral nutrient sources with effective microorganisms (EM) on the N, P and K concentrations in cotton plants

Treatments	Nitrogen (g kg^{-1})	Phosphorus (g kg^{-1})	Potassium (g kg^{-1})
T_0	19.7	2.20	10.58
T_1	22.8	2.50	10.74
T_2	21.3	2.50	20.44
T_3	27.1	2.80	20.11
T_4	29.4	2.94	20.11
T_5	27.5	2.95	20.47
T_6	28.5	2.95	20.46
T_7	28.9	2.97	20.51
LSD	1.75	0.02	1. 66

LSD represents least significant difference using Duncan's test at the 5% probability level.

3.3. Economic considerations

Data in Table 4 indicate that addition of organic and mineral N increased the financial returns relative to that achieved without N. Addition of full recommended NPK with EM + OM (T_7) increased net return by US$ 350, representing a 129% rise in net income. Application of 1/2 NPK + EM + OM (T_6) resulted in a net return of US$ 270 with 94% rise in net income, a value very close to that obtained by applying full NPK (T_4). The net returns of both treatments were almost the

Table 4
Comparative analysis of various treatments (per hectare) for their potential to give an optimum economic yield

Treatment	Grass income (US$)	Variable cost (US$)	Net income (US$)	Incremental income (US$)	Net return (US$)	VCR	RII (%)
T_0	359	–	359	–	–	–	–
T_1	438	17	421	62	45	3.67	17
T_2	431	5	426	67	63	14.73	19
T_3	539	22	517	159	137	7.35	44
T_4	815	93	722	363	270	3.90	101
T_5	676	51	625	266	215	5.21	74
T_6	765	68	697	338	270	4.97	94
T_7	938	115	823	464	350	4.05	129

VCR = value cost ratio; RII = relative increase in income.

same. The yields, net incomes and relative increases in income in T_7 and T_4 were relatively higher than T_6, but the initial expenditure involved in the two treatments was 41% and 26% higher than T_6 and farmers are always reluctant to pay more. After considering the cost of OM and EM used in T_6 and the cost of extra seed produced and fertilizer used in T_4, it is estimated that almost 50% of mineral fertilizer was saved by the integrated use of organic materials and EM. In addition to economic and monetary benefits, a 50% save in mineral fertilizer would have a significant effect on the environment and human health, energy conservation, soil quality and health. In a rice–wheat rotation in India, substitution of up to 50% of mineral NPK by the application of green manure and farmyard manure has been reported by Yaduvanshi (2003). Similarly, Roy et al. (2002) reported that 25% of the crop's N requirement can be met through farmyard manure and legume green manuring, thereby reducing N fertilizer requirements by 25%. The economic benefits of EM with OM in wheat under similar soil and environmental conditions were also reported by Hussain et al. (1999), who estimated a 38% saving in mineral fertilizer by the use of IPNMS. Most of the researchers used value cost ratio (VCR) for analysing economic benefits and financial considerations. It was observed that VCR did not coincide with grain yield and net return (Table 4). Instead, the relative increase in income (RII) used by Yinbo et al. (1997) seemed to be more appropriate for economic analysis of different inputs.

3.4. Environmental considerations

Modern industrial production of fertilizer N demands large inputs of energy in the form of natural gas, a finite natural resource; thus, fertilizer constitutes a major energy cost. NO_3^- supplied in excess of plant requirements may leach into groundwater aquifers, contaminating wells and placing human health at risk. In wet soils, denitrifying bacteria convert nitrate to N_2O, a greenhouse gas that has an energy reflectivity per mole 180-fold higher than that of CO_2. Thus, the use of fertilizer N may contribute to global warming. The consequences of these disequilibria are unclear, but prudence dictates that further perturbations of this major natural cycle be minimized. It emphasizes the importance of developing new production methods that are sustainable both agronomically and economically. They should be environmentally benign and should produce food that is safe for human consumption. The great challenge lies in devising more sustainable farming systems without compromising food production levels. The present study indicates that use of organic manures together with bacterial inoculation can minimize the use of synthetic fertilizer.

4. Conclusions

The investigation presented in this study indicates some distinct benefits of combined application of organic and inorganic nutrient sources together with EM over full supply of OM or inorganic fertilizer. The results confirm that besides increasing the crop yield, such practices save mineral N fertilization which has potential effects on sustainable agricultural production in soils low in organic matter. In addition, the possibility of sustaining the soil ecology and the environment cannot be ignored. The highest concentration of NPK in plants (with both mineral and organic nutrients + EM) demonstrated more efficient use of applied nutrients by organic and microbial application. More intensive and systematic studies are required to provide a better understanding of the usefulness of EM and organic manuring technology in making crop production a more profitable income generating activity for farmers.

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