Organic farming of rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system: a review

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Abstract

Sustainability problem caused by factor productivity decline due to indiscriminate use of chemical fertilizers and pesticides in rice-wheat cropping system can be solved with production of the cropping system under organic farming. Organic farming enhances soil organic carbon, available phosphorus content and microbial population/ enzymatic activity of soil thus making it sustainable for organic crop production. Use of different organic amendments in combinations and in a cumulative manner can meet the nutrient requirement of organic rice and wheat in rice-wheat cropping system. The main weed control strategies used in organic farming of rice-wheat cropping system is often combine cultural or husbandry techniques with direct mechanical and thermal methods. Pests are generally not a significant problem in organic system, since healthy plants living in good soil with balanced nutrition are better able to resist pest and disease attack. However, commercial production of biopesticides containing different bacteria, fungi and viruses has been undertaken to control certain insects, pests and diseases in organic crop production systems. Owing to positive influence of organic components in rice-wheat cropping system, it is therefore, be assumed that those farmers who adopted organic management practices, found a way to improve the quality of their soil, or at least stemmed the deterioration ensuring productive capacity for future generations.

Keywords: Rice, fungi, organic farming, wheat and organic carbon.

Introduction

The rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system occupies about 28.8 million hectares mainly spread over Asia’s five countries, namely, India, Pakistan, Nepal, Bangladesh and China (Timsinia and Connor, 2001; Prasad, 2005). In India rice-wheat cropping system covers about 12 million hectares spreading over states of Punjab, Haryana, UP, Bihar, West Bengal, Himachal Pradesh, Uttarakhand, Madhya Pradesh and Rajasthan. Rice-wheat cropping system accounts for about one-fourth of total food grain production of South-East Asia (Abrol *et al*., 1997) and about 31% of the total food grain production of India (Kumar *et al*., 1998; Prasad, 2005). This signifies the contribution of rice-wheat cropping system in meeting food requirements of the country. The rice-wheat cropping system, which is considered as the backbone of food self-sufficiency, is however facing a sustainability problem due to practices of modern production system with indiscriminate use of chemical fertilizers and pesticides (Nambiar, 1994; Duxbury *et al*., 2000; Ladha *et al*., 2000; Yadav *et al*., 2000; Prasad, 2005). The concerns like declining factor productivity (Biswas and Sharma, 2008; Patil, 2008; Yadav, 1998; Yadav, 2008), depletion of soil organic carbon and mineral nutrients content (Prakash *et al*., 2008), water logging and salinization, increasing nitrate concentration in well water (Singh *et al*., 1995) etc are the consequents of modern rice-wheat production system with unbalanced and injudicious use of chemical fertilizers and pesticides. The adverse effects of these chemicals are clearly visible on soil structure, microflora, quality of water, food and fodder. The quality of produce is also deteriorated due to entry of chemical residues in
the plant body and then to food chain. The emerging scenario necessitates the need of adoption of the practices which maintains the soil health, keeps the production system sustainable and provides qualitative food for meeting the nutritional requirements of human beings. Organic farming is one of the practices to make rice-wheat cropping system more sustainable without adverse effects on the natural resources and the environment (Stockdale et al. 2001).

According to a global survey conducted by Ockologie and Landbau (SOUL) (Formation of Ecology and Agriculture) of Germany, organic food in 2003 was produced on only 5% of the world cultivated area. Austria had the highest percentage of its cultivated area under organic farming followed by Switzerland, Italy, Finland, Denmark, Sweden and Czech Republic. India had the least percentage of cultivated area under organic farming. There is thus considerable scope to increase the area under organic farming in India. The global market for organically produced foods in 2005 was estimated at US $ 31 billion (Rs 14,300 crores) (Bhattacharya and Gehlot, 2003) and is likely to increase to US $ 102 billion by 2020. Since India’s share in global market for organic food is currently less than 1%, there is tremendous opportunity to increase it.

Awareness about improved quality of food products, problems of health hazards and environmental issues both at global and national level is increasing in recent years. There is a great demand for high quality products and organically grown foods in the international market and can capitalize on its potential to go for organic farming on a large scale. India, with its varied agro-climatic conditions and agricultural biodiversity, is most suited for organic farming. It is necessary to educate the farmers about the scientific methods of organic farming so that their income will increase gradually. Organic farming is also preferred because of increasing consumer demand for safe, high quality, ethical organic foods. Organically produce also fetches good returns.

Components of organic farming

Nutrient Sources
The aim of nutrient management in organic systems is to optimize the use of on-farm resources and minimize losses. Organic materials such as farmyard manure, compost, vermicompost, biogas slurry, green manures, crop residues, biofertilizers and cover crops are valuable source of nutrients to improve the growth and yield attributes, yield, nutrient uptake, grain quality and soil fertility. The values of these sources of nutrients are reviewed separately for rice and wheat.

(a) Farmyard manure (FYM)
FYM or farmyard manure is bulky organic manure resulting from decomposed mixture of dung and urine of farm animals along with the litter (bedding material). Average, well rotted FYM contains 0.5-1.0% N, 0.15-2.0% P₂O₅ and0.5-0.6% K₂O. Desired C:N ratio in FYM should not exceed 15-20 (Bhattacharyya and Tandon, 2002). Application of FYM is of greater significance for sustainability as it has great potentiality to improve the physical properties of soil besides supplying nutrients. Each of these physical properties has large practical implication in maintaining soil as a medium of production and great role in halting environmental degradation. Maintaining them and improving them in long run is essential part of sustaining the ecosystem.

Farmyard manure is a product of microbial activity and contains large number of microbial population. Application of farm yard manure can increase the microbial activity in the soil both by activating the microbial action and by aiding the multiplication of microbial population. Due to these properties, application of farm yard manure is in perfect tune with biological requirement of soil and helps to build the soil on sustainable basis. The capacity of soil to release, store and supply the plant nutrients is based on this microbial activity of soil. Large number of reports is available in the literature to show the enhanced microbial activity by application of farmyard manure. Increased organic carbon by application of FYM has been reported to help in increased population of bacteria, actinomycetes and fungi (Gaur et al., 1990). Like many other organic manures, farmyard manures leaves behind definite beneficial residual effects to the succeeding crop. The total nutrients entering labile form in subsequent year’s beneficial residual effects are derived by:

(a) Part of total nutrients entering labile form in subsequent years
(b) Improved physical properties help in soil enrichment as well as improved physical properties of soil which ultimately help in crop production in many ways.
Improved yield of succeeding crop by FYM application to preceding crop was reported from as early as 1932 at Pusa in the experiments involving crop rotation. Many other workers have reported recently about beneficial residual effect of FYM application. Singh et al., (1999) reported that N uptake was increased in succeeding year after application of FYM as compared to fertilizing through inorganic sources. Ramusseen and Smiley (1989) found that paddy yields were increased by 6 q ha⁻¹ as a residual effect of FYM applied to previous crop. Nimje and Seth (1988) found the residual beneficial effect of FYM applied to soybean crop on succeeding crop of maize.

**Rice**

Shanmugam and Veeraputhran (2001) revealed that application of farmyard manure (FYM) at 12.5 t ha⁻¹ significantly increased the growth and yield attributes and yield of rice. Bridgit and Potty (2002) found that increasing the FYM level increased the number of roots per plant and average root length. Maximum correlation was observed between root number per plant and grain yield, straw yield and total biomass, followed by the difference in total dry weight between flowering and panicle initiation stages. Bhattacharya et al. (2003) recorded highest plant height at 45 and 90 days after transplanting with 9.0 t FYM ha⁻¹. The application of 7.0 t FYM ha⁻¹ resulted in the highest dry matter accumulation at 45 (327.1 and 319.8 g m⁻²) and 90 days after transplanting (648.4 and 651.1 g m⁻²) and the dry weight at tillering and flowering growth stages.

The beneficial effects of FYM on grain and straw yield have been reported by many workers (Mahapatra et al., 1987; Tiwari et al., 1998 and Satapathy, 1999). Summarizing the work done in China, where FYM is widely used, FAO (1978) reported that application of 30-40 tonnes FYM ha⁻¹ increased the yield ranging from 24 to 89% as compared to control. Meelu and Morris (1984) revealed that application of 12 tonnes FYM ha⁻¹ to rice in rice-wheat cropping system results in a saving of 40 kg N/ha and 20 kg P₀₂O₅ and 30 kg K₂O ha⁻¹ in succeeding wheat crop. Mahapatra et al. (1987) and Rajput and Warri (1992) reported that application of 50-60 kg N ha⁻¹ through FYM increased the yield by 64% over control. Tanveer et al. (1993) and Thakur and Patel (1998) reported that incorporation of FYM @ 5 t ha⁻¹ significantly increased the yield and yield attributing characters of rice over control. Further investigations revealed that grain yield was highest with FYM composted with 2.5 ppm Zn plus green manure (Gliricidia). The results of a field experiment conducted for 2 years during 1992-93 and 1993-94 in Madhya Pradesh showed that application of FYM @ 10 t ha⁻¹ significantly increased the rice yield and succeeding wheat in both years compared to control (Singh et al., 1996).

Application of 10 t FYM ha⁻¹ in rice-wheat system significantly increased N, P and K uptake by 4.0, 7.8 and 7.6% as compared with control (Singh et al., 2004). Quyen and Sharma (2003) studied the comparative effects of organic and conventional farming on scented rice at research farm, IARI, New Delhi and reported that application of FYM significantly increased N and P uptake by both grain and straw over control and was found statistically equal to 60 kg N +13 kg P +17 kg K ha⁻¹. Modak and Chavan (2000) studied the response of rice to FYM in black calcareous soil of Palghar (Thane), the uptake of N, P and K by grain and straw increased due to application of FYM. Sharma and Sharma (2002) studied the effect of nutrient management on sustainability of rice (Oryza sativa)-wheat (Triticum aestivum) cropping system revealed that FYM @ 10 t ha⁻¹ increased the grain yield of rice-wheat system by 1.2-1.3 t ha⁻¹, straw yield by 0.7-2.3 t ha⁻¹, N uptake by 38-45 kg ha⁻¹, P uptake by 7-10 kg ha⁻¹, K uptake by 25-42 kg ha⁻¹. Zia et al. (1992) recorded an increase in N uptake of rice due to application of Sesbania aculeata, FYM and rice straw; the additional uptake amounts were in the order of Sesbania aculeata > FYM > rice straw.

The beneficial role of FYM in improving the physical, chemical and biological properties of soil have been reported by Gaur (1984), Larsen and Clapp (1984) and Hegde (1998). Application of FYM significantly increased organic carbon content (Vig and Bhumla, 1970 and Mukherjee and Gaur, 1980); available N (Kanwar and Prihar, 1962) and available P and K (Schmid et al., 1977). Gill and Meelu (1980) reported that organic carbon content and available P increased from 0.23 to 0.30% and 7 to 12 kg ha⁻¹, respectively with the application of FYM @ 12 t ha⁻¹ for 24 years in rice-wheat rotation. Singh et al. (2005) reported that bulk density reduced to 1.32 as compared to 1.45 in control, porosity increased by 5 per cent as compared to control, WHC increased by 5 per cent as compared by control by application of FYM at 10 t ha⁻¹ in rice. Gupta (1995) recorded that the moisture percentage at 0-15 cm soil depth was highest (19.19%) with FYM followed by pig manure and poultry manure, whereas at 15-30 cm soil depth the moisture percentage was highest with tank clay and NPK fertilizer. He concluded that application of organic manures like pig manure, poultry and FYM were beneficial to rice cultivation in Alfisols due to retention of higher soil moisture in the rooting zone. According to Prasad and Mishra (2001) addition of fertilizer-N
tended to decrease soil organic carbon (SOC) after rice harvest, while application of FYM prevented the decline in SOC. Application of FYM and fertilizer-N increased alkaline permanganate oxidizable N. Lian (1993) reported from the long-term experiments of Asia that effects of continuous manure application increased soil organic matter and nitrogen content, but the increase was less significant in tropical and subtropical countries than in temperate regions due to more rapid turnover of organic carbon. Bellakki et al. (1998) marked increase in WHC of lateric soil by application of different organic manures. The increase was in the range of 19.3 to 27.4% over NPK alone. They also perceived that application of FYM recorded the highest WHC i.e. 46.4% followed by mushroom spent, rice straw compost and composted coir pith. Ramteke et al. (1998) detected that the application of FYM @ 10 t ha\(^{-1}\) significantly reduced the bulk density of soil as compared to the initial value after harvest of rice. Singh et al. (1988) and Prasad and Mishra (2001) stated that the application of FYM increased organic carbon, available NPK as compared to control. This may be due to decomposition and mineralization of organic matter. Kumar and Singh (1997) noted that application of FYM @ 10 t ha\(^{-1}\) to both rice and wheat crop increased available nitrogen and phosphorus status of soil over no application of FYM and initial value. The available potassium status found to be declined with FYM application as compared to initial values.

Kharub (2008) reported that rice productivity was at par under inorganic and organic fertilization where farmyard manure (FYM) application was 22.5 t ha\(^{-1}\) in rice.

**Wheat**

Thakur and Patel (1998) found that application of FYM increased dry matter production, leaf area index, leaf area duration, crop growth rate, net assimilation rate and relative growth rate of wheat. Tripathi and Gehlot (1999) reported that FYM application significantly increased cation exchange capacity (CEC) of wheat roots grown on saline-sodic soil. The growth parameter, only plant height was significantly correlated with root CEC. Dudhat et al. (1997) reported that application of FYM significantly increased effective tillers plant\(^{-1}\) and ear length of wheat.

Increase in P, Zn and Ca contents and uptake by grain and straw with FYM application has been reported by Golakiya et al. (1990). In a long-term field experiment at Pantnagar, highest N, P and K uptake by crops was recorded with the application of FYM at 15 t ha\(^{-1}\) (Bhardwaj and Tyagi, 1994). Ghosh and Saha (1997) observed a significant increase in N uptake by the grain. Rawat and Pareek (2003) reported that the effects of FYM on N, P and K content of wheat grain and straw increased with increasing rates of FYM and the N, P and K uptake of the crop also increased with increasing rates of FYM. Singh and Agarwal (2004) reported that application of 10 t FYM ha\(^{-1}\) in rice-wheat cropping system resulted in significantly higher N, P and K uptake as compared with control. Keshwa and Singh (1988) observed that application of FYM at 25 t ha\(^{-1}\) significantly increased uptake of nitrogen and phosphorus by wheat. Maskina and Meelu (1984) observed the residual effect of FYM applied rice at 12 t ha\(^{-1}\) on the succeeding wheat was equivalent to that of 30 kg N and 13 kg P ha\(^{-1}\).

Werner et al. (1988) noted that application of FYM over a period of 24 years increased the organic carbon content and total N content of the soil. Similar increase in organic carbon and available P in soil due to FYM application have been reported by Singh et al. (1988). Bhagat and Verma (1991) revealed that incorporation of FYM resulted in higher percentage of water stable aggregate, lower bulk density, higher porosity, higher available water holding capacity and higher hydraulic conductivity. Zia et al. (1992) studied the effect of green manure, FYM and rice straw on soil fertility, and found that residual soil N was highest following Sesbania aculeata green manure and lowest following rice straw incorporation; residual soil P was highest following FYM application, whereas residual soil K was highest following rice straw incorporation. The increase in infiltration rates, organic carbon content, available N, P and K in soil due to FYM application was reported by More (1994). Sharma et al. (1993) reported an increase in organic carbon, total N and available N, P and K and a decrease in bulk density with the application of fertilizer levels or FYM compared to the initial or unmanured plots. Singh and Yadav (2006) conducted an experiment during *rabi* seasons of 2001-02 and 2002-03 on loamy sand soil of Rajasthan, India revealed that application of organic material increased the dry matter accumulations, height, effective tiller number, grain and straw yields of wheat over no organic materials irrigated by high RSC water. Among the organic materials, application of poultry manure at 5 t/ha was found superior to the rest of the organic materials, whereas FYM and Tephrosia at 10 t/ha were recorded equally effective over control.

Behera et al. (2009) reported that application of available organic sources, particularly FYM and poultry manure along with full recommended dose of NPK fertilizers to wheat was essential for improving productivity, grain quality, profitability, soil health and sustainability of wheat-soybean system. Kharub...
(2008) reported that protein content in wheat increased with increase in the dose of FYM, but the highest protein content (11-24%) was recorded under inorganic fertilizer.

**Green manuring**

Organic farming relies on soil health and cycling of nutrients through the soil using natural processes. Green manures perform the vital function of fertilization, in concert with the addition of animal manures if those are used. Application of green manure has been found quite promising in enhancing crop yield and fertilizer saving (Dixit, 2007). Green manuring is the plowing under or soil incorporation of any green manure crops while they are green or soon after they flower. Green manures are forage or leguminous crops that are grown for their leafy materials needed for soil conservation. It is found that about 18 grain legume species are important for green manuring in various rice farming situations of Asia. In the irrigated environment of tropics and subtropics, green legumes can be grown in rotation with one or more rice crops per year (Buressh and Datta, 1991).

![Image](image-url)

Table 1. Biomass production and N accumulation in some common green manures (Abrol and Palaniappan, 1988)

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Botanical Name</th>
<th>Growing Season</th>
<th>Output in 40–60 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunnhemp</td>
<td>Crotolaria junccea</td>
<td>wet</td>
<td>21.2</td>
</tr>
<tr>
<td>Daincha</td>
<td>Sesbania aculeata</td>
<td>wet</td>
<td>18.3</td>
</tr>
<tr>
<td>Pillipesara</td>
<td>Phaseolus trilobus</td>
<td>wet</td>
<td>8.0</td>
</tr>
<tr>
<td>Mungbean</td>
<td>Vigna radiata</td>
<td>wet</td>
<td>15.0</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Vigna sinensis</td>
<td>wet</td>
<td>20.0</td>
</tr>
<tr>
<td>Guar</td>
<td>Cyamoposis tetragonoloba</td>
<td>wet</td>
<td>15.5</td>
</tr>
<tr>
<td>Barseem</td>
<td>Trifolium alexandrium</td>
<td>dry</td>
<td>21.2</td>
</tr>
</tbody>
</table>

The adoption of green manuring depends upon the agroclimatic conditions. Broadly the following two types of green manuring can be thought of: (a) Green manuring in situ: In this system, green manure crops are grown and buried in the same field which is to be green-manured. Sesbania (Sesbania aculeata) is known as dhanich, or sawri, is a common leguminous green-manure crop of this type in India. It is a shrubby annual, growing to several feet in height, the branches and leaf stalks armed with small, weak prickles. The pinnate leaves bear forty-one to eighty-one narrow leaflets and the pale yellow, red-dotted flowers are borne three to six in a loose raceme. The pods are long and very narrow. Sesbania is better adapted to wet lands and thrives at higher altitudes, will endure considerable drought and salinity in the soil and will grow on very poor land. It is not useful for forage and is consequently grown as a green manure only. Sesbania aculeata is said to have a strong, deep root system and this fact has been mentioned as an advantage when it is desirable to open up a subsoil. (b) Green leaf manuring: Green leaf manuring refers to turning into the soil green leaves and tender green twigs collected from shrubs and trees grown on bunds, waste lands and nearby forest areas. *Leucaena leucocephala* is a thornless long-lived shrub or tree which may grow to heights of 7-20 m. Leaves are bipinnate with 6-8 pairs of pinnate bearing 11-23 pairs of leaflets 8-16 mm long. The inflorescence is a cream coloured globular shape which produces a cluster of flat brown pods 13-18 mm long containing 15-30 seeds.

**Rice**

Manguiat et al. (1997) reported that immediate sowing of rice after green manure incorporation did not negatively affect the growth and development of upland rice. Chandra and Pareek (1998) observed that incorporation of different green manuring species of *Sesbania* increased the plant dry weight from 7.1 to 25.2% at different intervals. All *Sesbania* species except 45 day-old *S. rostrata* produced significantly more plant dry weight than control at 51 DAT, however, different species did not differ significantly. *Sesbania rostrata* (60 day-old), however, recorded the highest plant dry matter at all growth stages. Total and effective tillers recorded at maturity showed the similar trend. Vaiyapuri et al. (1998) reported that application of 12.75 t/ha *Sebania* green manure in rice recorded the highest plant height, LAI, number of tillers per hill and dry matter accumulation of rice. Hemalatha et al., (2000) observed that in situ incorporation of dhanicha at 12.0 t ha⁻¹ recorded the best values for plant height (97.61 cm), number of tillers per hill (19.55), leaf area index (6.85), dry matter production (13848 kg/ha) and days to 50% flowering (101 days). Singh et al. (2000) reported that application of FYM and GM increased the root length density significantly over control. The FYM applied plots showed higher root–length density (4.52 cm cm⁻³) than
GM (3.67 cm cm$^{-3}$). Mukherjee and Singh (2001) revealed a significant effect of Sesbania green manuring on plant height at 50 and 70 days after transplanting and at harvest. Summer green manuring of Sesbania before rice transplanting recorded significantly more number of tillers at 30 and 50 days after transplanting over residue incorporated, residue burnt and residue removed treatments. Vaiyapuri and Sriramachandrasekharan (2002) revealed that incorporation of 12.5 t ha$^{-1}$ of Sesbania aculeata recorded the highest plant height (87.3 cm), number of tillers hill$^{-1}$ (15.4) and LAI (7.9).

Green manuring of Sesbania equivalents to 45 kg N/ha which gave 20% more yield than the control and the response was 8.8 kg grain per kg N (Maurya and Ghosh, 1972). Beri and Meelu (1981) observed that green manuring gave more yield of rice than that 60 kg urea-N ha$^{-1}$. Positive benefits of Sesbania green manuring on grain and straw yield have also been reported by many other workers. (Maurya and Ghosh, 1972; Tiwari et al., 1980: Rana et al., 1988; Becker and Ottow, 1991; Tiwari et al., 1998). At Cuttack, rice cv. Gayatri and dhaincha (Sesbania aculeata) were either mixed-sown in different arrangements (parallel lines and mixed broadcasting) in dry soil or rice seedlings were transplanted in plots grown with pure dhaincha after the accumulation of water. The grain yield of both direct-sown and transplanted crops increased with dhaincha green manuring compared with control (without green manuring). They commented that the increase in yield under green manuring was due to higher panicle weight, which is probably due to a combined supply of N following decomposition of organic matter added through the dhaincha. Grain yield obtained with Sesbania aculeata was equivalent to 90 kg ha$^{-1}$ in non-scented rice (Mahapatra and Sharma, 1996). The results of the experiments conducted at IARI showed that Sesbania green manuring during summer months (May-June) increased grain yield of rice by 0.4 t ha$^{-1}$ (Sharma et al., 1995). Bhattacharyya and Mandal (1999) reported that green manuring increased yields of rice by 18.2-54.9% on sandy loam soil and by 21.7-42.9% on silty loam soil and partially compensated for the effects of water stress. Aulakh et al. (2000) conducted a 4-year replicated field experiment with irrigated rice-wheat rotations on a sandy loam soil to evaluate the effects of incorporating cowpea (Vigna unguiculata) or Sesbania (Sesbania aculeata) green manuring (GM) on crop productivity. Rice grain yields with pre-transplant incorporation of 20 and 40 t GM ha$^{-1}$ ranged from 5.18 to 5.81 t ha$^{-1}$, Khan et al. (2000) reported that Sesbania aculeata increased rice yield by 7 q ha$^{-1}$. An increase of 3 q ha$^{-1}$ was observed in comparison to beushening (Beushening is cross ploughing in standing water under lowland rice ecosystems when rice plants are approximately 45 days old). Dhiman et al. (1999) revealed that the comparative effects of organic manures (green manuring and FYM at 20 t ha$^{-1}$) and chemical fertilizers on scented rice in rice-wheat sequence. Green manuring of dhaincha (Sesbania aculeata) before transplanting rice gave higher grain yield of rice than other treatments. Hemalatha et al. (2000) observed that in situ incorporation of dhaincha at 12 t ha$^{-1}$ increased the grain yield by 18% and straw yield by 16% over no organic manure, owing to increase in growth and yield-attributing characters of rice. Mehla et al. (2000) reported mean grain yield of 6.89, 6.74, 6.16 and 5.43 t ha$^{-1}$ with GM, FYM, ash and control treatments, respectively.

Sriramachandrasekharan et al. (1996) observed that Sesbania aculeata green manure resulted in higher N, P and K uptake (mg pot$^{-1}$) by rice grain and straw as compared green manure with Sesbania speciosa, Crotalaria juncea, Azolla microphylla, cowpea, FYM, composted pith and paddy straw.

Tiwari et al. (1980) observed that Sesbania green manure increased the N, P, and K contents in plants and their availability in soil. Similarly, Sharma and Mishra (1988) observed a marginal increase in N content of straw due to application of organic materials. Sharma et al. (1995b) observed that incorporation of Sesbania green manure and mungbean residue increased rice plant-N yield over pre-fallow rice by 22 and 28 kg N ha$^{-1}$, respectively, in the first experiment and by 15 and 18 kg N ha$^{-1}$, respectively, in the second experiment. Chandra and Pareek (1998) reported that N uptake by rice plant from GM treated plots was more than the untreated plots but significant differences were obtained only at 51 DAT. Saha et al. (2000) observed that green manuring registered significantly higher P uptake, which was 8.4 higher over fallow. Sesbania green manure resulted in N and P uptake similar to 120 kg N + 13 kg P + 17 kg K ha$^{-1}$ and 120 kg N + 26 kg P + 34 kg K ha$^{-1}$, respectively (Quyen and Sharma, 2003).

Sriramachandrasekharan (2001) studied the effect of Sesbania aculeata, S. speciosa, Crotalaria juncea, paddy straw, powdered farmyard manure or composted raw coirpith, twenty-eight-day-old rice cv. IR 60 seedlings on nutrient uptake. The highest values for uptake of N (399.4 mg pot$^{-1}$), P (49.82 mg pot$^{-1}$), K (403.2 mg pot$^{-1}$), Zn (1059.9 μg pot$^{-1}$), Fe (18.28 mg pot$^{-1}$), Mn (6.69 mg pot$^{-1}$) and Cu (693.3 μg pot$^{-1}$) in IR 60 were recorded with the addition of S. aculeata. Duhan et al. (2001) observed that application of GM, in general, increased the K uptake from 2.9 to 4.6 kg ha$^{-1}$ in rice grain, and from 2.4 to 3.9 kg ha$^{-1}$ in straw. Mahapatra et al. (2002) observed that higher yield values with summer legumes may be attributed to...
more nutrient contribution towards nutrition of rice crop as evidenced from high ammonium-N in soil. Hemalatha et al. (1999) also reported that grain quality (amylose and crude protein content) was better with Sesbania aculeate as compared to control.

Hattab et al. (1998) observed an improvement in the quality characteristics of rice, especially the crude protein content in rice with Sesbania green manure. Chahal et al. (1999) observed that green manuring resulted in 14-15 per cent increase in uptake of Fe and Mn and 5 to 6 per cent increase in uptake of N, Zn and Cu by rice over no-green manure treatment. Dwivedi and Thakur (2000) reported significantly higher NPK and protein contents in rice with application of dhaincha green manure and biogas-slurry application.

Green manuring may prevent leaching loss, render unavailable forms of nutrients into available forms and increase permeability and drainage capacity of soil besides ensuring steady supply of nitrogen throughout the growth period of following crop (Krishna Rao et al., 1961). Agboola (1974) highlighted the capacity of green manuring to recycle the leached plant nutrients. This, he stated, was accomplished by the absorption of nutrient from the lower depths by deeper roots of legumes.

Van de Goor (1941) stated that the yield increases following green manuring are not only due to supply of nitrogen but also due to increased supply of phosphorus and potassium. Several workers have reported a solubilizing effect of decomposing organic matter on P, K and trace elements (Lockett, 1938; Copeland and Merkle, 1941; Kute and Mann, 1969; Debnath and Hajra, 1972 and Nagarajah et al., 1986). This may be due to the release of CO2 and weak acids which act on insoluble soil minerals as reported by Rogers and Giddens (1957) and Agboola (1974) and also due to the release of these minerals from green manure (Nagarajah et al., 1986). Maurya and Ghosh (1972) and Chatterjee et al. (1979) observed an increased cation exchange capacity with green manuring.

Incorporation of green manure crops into the soil had shown to increase soil organic carbon (Williams et al., 1957; Havangi and Mann, 1970; Swarup, 1987; Chatterjee et al., 1979; Sharma and Mishra, 1988 and Cassman et al., 1996).

Bhardwaj and Dutt (1995) while examining the effect of legume green manures on some microbiological properties in an acid rice soil, found significant improvement in the microbial biomass, dehydrogenase activity, and bacterial population in the field soil green manured for rice for 3 years compared with fertilized soil.

**Wheat**

Saha et al. (2000) observed that dry matter production of wheat was significantly influenced by preceding green manure crops. Sharma et al. (2001) reported that application of Leucaena leaf mulch at 2 t ha\(^{-1}\) and its incorporation at 30 days after maize harvest was beneficial for conserving soil moisture and improving seed production of rainfed wheat. Budhan et al. (1996) observed that application of white lead tree or subabul (Leucaena leucocephala) leaf biomass significantly increased plant height and yield-contributing characters of bread wheat (Triticum aestivum). Gangwar et al. (2004) observed that application of L. leucocephala loppings resulted in higher number of tillers m\(^{-2}\), grains ear\(^{-1}\) and 1000-grain weight of wheat.

Sharma et al. (1995) reported that Sesbania green manuring and mungbean residue incorporation in rice increased grain yield of succeeding wheat by 0.3-0.7 t ha\(^{-1}\). Sharma and Prasad (1999) compared Sesbania aculeata and S. rostrata and found that both the species were similar in their effect and increased the succeeding wheat yield by 0.2-0.3 t ha\(^{-1}\). Palled et al. (2000) reported that application of Subabul increased the grain and straw yields by 11.7 and 8.6%, respectively over vermicompost due to lower C:N ratio, faster rate of mineralization, more moisture conservation and higher availability of nutrients. Kumar and Sharma (2000) found that dhaincha and blackgram had significant positive effects on the growth and yield attributes of wheat which ultimately resulted in significantly higher grain yield of wheat than control. Sharma et al. (2001) observed that air-dried Leucaena leaves were applied as surface mulch at varying levels, viz., 0, 2, 4 and 6 t ha\(^{-1}\) as main plot treatments and timings of incorporation viz., 0, 15, 30 and 45 days after harvest of maize as sub-plot treatments. Application of mulch increased wheat grain and straw yield significantly. The study indicated that application of Leucaena leaf mulch at 2 t ha\(^{-1}\) and its incorporation at 30 days after maize harvest was beneficial for improving productivity of rainfed wheat. Prakash and Bhushan (2003) reported that 3137 kg ha\(^{-1}\) green Leucaena leaves containing 3% N on dry weight basis and incorporated into the soil 15 days before wheat crop sowing increased wheat yield at par with 100 kg N applied through urea.

Mandal et al. (1999) indicated that Sesbania green manuring before rice resulted in reduction in bulk density and increase in soil aggregation which in turn increased infiltration and percolation rate and hydraulic conductivity of soil during growing period of succeeding wheat. These results are in confirmation
of conclusion made by Joshi et al. (1994). The recent reports from IARI showed that Sesbania green manuring increased soil organic carbon over summer fallow by 0.030-0.162%, Kjeldahl N by 0.005-0.003% and available P by 4.0-6.9 kg ha\(^{-1}\) (Sharma et al. 2000). Chaphale et al. (2000) also reported that the addition of green manure (Gliricidia) over a period of 5 years led to increase in organic carbon, total N, available N, P, K and water holding capacity, but bulk density of soil decreased as compared to control.

**Green manuring + Biofertilizers**

Microbial inoculants or biofertilizers are important components of organic farming, which help to nourish the crops through required nutrients. These microbes help to fix atmospheric nitrogen, solubilize and mobilize phosphorus, translocate minor elements like zinc, copper, etc., to the plants, produce plant growth promoting hormones, vitamins and amino acids and control plant pathogenic fungi, thus helping to improve the soil health and increase crop production. Biofertilizers like Rhizobium, Azotobacter, Azospirillum and blue-green algae (BGA) are in use since long. These organisms fix atmospheric nitrogen and supply it to plants. Hence, called as bio fertilizers. The bacterial biofertilizers contribute 20-30 kg N/ha/season. Rhizobium inoculant is used for leguminous crops. Azotobacter can be used with crops like wheat, maize, mustard, cotton, potato and other vegetable crops. Azospirillum inoculants are recommended mainly for sorghum, millets, maize, sugarcane and wheat. Blue-green algae belonging to genera Nostoc, Anabaena, tolypothrix and Aulosira fix atmospheric nitrogen and are used as inoculants for paddy crop grown both under upland and low land conditions. However, the inoculants are most effective under low land rice cultivation and contribute 20-30 kg N per ha per season with better quality of grains. Anabaena in association with water fern Azolla contributes nitrogen up to 60 Kg/ha/season and also enriches soils with organic matter.

The term biofertilizer or microbial inoculants can be defined as the preparation containing strains of microorganisms which can augment the microbiological process such as nitrogen fixation, phosphate solubilization or mineralization, excretion of plant growth promoting substances or cellulose or lignin biodegradation in soil, compost or other environments (Gaur, 2006).

The biological nitrogen fixation system can be grouped into three categories: (i) Symbiotic non-leguminous symbiotic system (ii) Legume- Rhizobia Symbiosis (iii) Other Symbiotic nitrogen fixing systems. An artificially prepared *Rhizobium* culture used for seed dressing of legumes before sowing. A specific *Rhizobium* culture for a specific legumes crop which has high ability for infection, nodulation, fixation and antibiotic resistance is needed (Bhattacharyya and Tandon, 2002).

Azotobacter is non-symbiotic free living nitrogen fixing soil bacteria recommended for cereals, vegetables and flowers. Application is generally done by seed/seedling treatment or soil application. Its foliar application is also reported. Both carriers based and liquid based Azotobacter fertilizers are available. The species of Azotobacter are known to fix on an average 10 mg of N/g of sugar in pure culture on a nitrogen free medium. Most efficient strains of Azotobacter would need to oxidise about 1000 kg of organic matter for fixing 30 kg of N/ha. This does not sound realistic for our soils which have very low active carbon status. Besides, soil is inhabited by a large variety of other microbes, all of which compete for the active carbon.

The blue-green algae (BGA) are often referred to as Cyanobacteria or Cyanophyta which is a phylum of Bacteria that obtain their energy through photosynthesis. The name "Cyanobacteria" comes from the colour of the bacteria, cyan (blue); the bacteria do not use or produce cyanide. Putative fossil traces of Gyanobacteria have been found from around 3.8 billion years which surely proves that Blue-green algae are among the most primitive life forms on Earth. Blue-green algae are filamentous, photosynthetic, aerobic N fixing organisms. More than 100 species of BGA are known to fix N. These are used as biofertilizer for wetland rice (paddy) and can provide 25-30 kg N ha\(^{-1}\). They also secrete hormones like IAA, GA and improve soil structure by producing polysaccharides, which help in the binding of soil particles resulting in better soil aggregation. BGA need all the plant nutrients for their growth and N- fixation. Optimum temperature for BGA is about 30-35°C and low temperature decrease their growth. The optimum pH for BGA growth in culture media ranges from 7.5 to 10.0 and its lower limit is about 6.5-7.0 (Kumar and Shivay, 2008). BGA are conspicuous due to their contribution to soil structure and erosion control. The surface blooms reduce erosion losses by binding together of soil particles (Gaur, 2006). Use of biofertilizers like BGA, azolla or azospirillum has been reported to increase the productivity of crops and residue the fertilizer N requirement substantially in rice-based cropping systems. Choice of appropriate biofertilisers and application at the recommended dose and time would go a long way in saving of fertilizer nutrients (Palaniappan and Annadurai, 2006).
Table 2. Important biofertilizers, their contribution in supplying nutrients and recommended dose of application (Gaur, 2006)

<table>
<thead>
<tr>
<th>Biofertilizers</th>
<th>Function/Contribution</th>
<th>Recommended Dose ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhyzobium</em></td>
<td>45-60 kg N ha⁻¹ (Mungbean)</td>
<td>2 kg ha⁻¹</td>
</tr>
<tr>
<td><em>Azotobacter</em></td>
<td>15-25 kg N ha⁻¹ (Wheat)</td>
<td>2 kg ha⁻¹</td>
</tr>
<tr>
<td><em>BGA</em></td>
<td>25-30 kg N ha⁻¹ (Rice)</td>
<td>1.5 kg ha⁻¹</td>
</tr>
<tr>
<td>Cellulolytic culture</td>
<td>Degradation crop residues and FYM</td>
<td>600 g ton⁻¹</td>
</tr>
<tr>
<td><em>PSB</em></td>
<td>10-15 kg P ha⁻¹ (soil)</td>
<td>600 g ha⁻¹</td>
</tr>
</tbody>
</table>

Table 3. Microorganisms used as biofertilizers (Verma and Bhattacharya, 1990)

<table>
<thead>
<tr>
<th>Contributing Microorganisms</th>
<th>Plant nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Symbiotic</td>
<td></td>
</tr>
<tr>
<td>a) <em>Rhizobium</em> (with legumes)</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>b) <em>Azolla</em> (<em>Azolla</em> and <em>Anabaena azolla</em>)</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>2. Associative Symbiotic</td>
<td></td>
</tr>
<tr>
<td>a) <em>Azospirillum</em></td>
<td>Nitrogen</td>
</tr>
<tr>
<td>3. Non-Symbiotic</td>
<td></td>
</tr>
<tr>
<td>a) <em>Azotobacter</em> (heterotrophs)</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>b) Blue-green algae (photoautotrophes)</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>4. Others</td>
<td></td>
</tr>
<tr>
<td>a. P Solubilisers &amp; Mineralisers</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Fungi: <em>Aspergillus</em>, <em>Penicillium</em></td>
<td></td>
</tr>
<tr>
<td>Bacteria: <em>Pseudomonas</em>, <em>Bacillus</em></td>
<td></td>
</tr>
<tr>
<td>b. P Absorbers (root fungus symbiosis)</td>
<td>Phosphorus and Zinc</td>
</tr>
<tr>
<td>VAM (<em>Vesicular Arbuscular Mycorrhiza</em>)</td>
<td></td>
</tr>
<tr>
<td>c. Cellulose decomposing microorganisms</td>
<td>Degradation crop residues</td>
</tr>
<tr>
<td>Bacteria: <em>Cellulomonase biazotea</em></td>
<td>(Cellulose rich materials)</td>
</tr>
<tr>
<td>Fungi: <em>Trichoderma virdi</em></td>
<td></td>
</tr>
<tr>
<td>Actinomycetes: <em>Thermonospora curvata</em></td>
<td></td>
</tr>
</tbody>
</table>

Rice
Quyen and Sharma (2003) reported that inoculation of BGA with *Sesbania* green manure (SGM) significantly increased plant height over control at 30 and 60 DAT, number of tillers m⁻² over FYM.

Shanmugam and Veeraputhran (2001) revealed that application of green manure (*Sesbania aculeata*) at 6.25 t ha⁻¹ with *Azospirillum* resulted in significantly shorter period for 50 per cent flowering, highest number of productive tillers m⁻², filled grains per panicle, panicle length and grain yield of rice (5282 and 5218 kg ha⁻¹).

Satapathy (1999) reported that the N uptake of rice was higher than in FYM, whereas the other organic manures were comparable to urea in N uptake. Fresh *Azolla*, *Aulosira* and *Azolla* compost also showed higher crop N uptake than FYM. Fresh *Azolla*, Azolla compost and *Eichhornia crassipes* were superior to urea, *Pistia stratiformes*, *Sesbania cannabina* green manure, *Aulosira* and FYM were comparable to urea for P uptake of rice.

Dwivedi *et al.* (2005) reported that combined application of green manuring and biofertilizers increased organic C by 0.01 to 0.22%, total nitrogen by 0.010 to 0.032% and available phosphorus by 1 to 7 kg ha⁻¹ in soil over control under rice-wheat cropping system. Sharma *et al.*. (2008) reported that inoculation of biofertilizers by root dipping in 1 g *Azotobacter* + 1 ml *Azospirillum* + 1 ml PSB each mixed in 1 liter water + soil application of each @ 525 g or mlha⁻¹ as basal recorded significantly higher grain and straw yield of wheat and N, P and K uptake over other treatments and control. Chinnumasy *et al.* (2006) reported that the biofertilizer combination BGA + PSB + VAMF + *Azospirillum* was best for improved growth and yield traits, nutritional status of rice and sustained soil (peat) fertility.

Wheat
Singh *et al.* (2002) reported build up of available N, P, K and organic C in the soil with combination of *Sesbania aculeate* and BGA applied to preceding rice over control. Mehra and Singh (2007) reported that the
combination of FYM, green manure, crop residue and biofertilizer (Azotobacter) with inorganic sources resulted in highest plant height (98 cm), no of tillers m$^{-2}$ (349), grain yield (41.36 q ha$^{-1}$) and straw yield (82.32 q ha$^{-1}$) of wheat and also highest N (144.99 kg ha$^{-1}$), P (36.40 kg ha$^{-1}$) and K (145.40 kg ha$^{-1}$) uptake by wheat. Khosravi et al. (1998) observed a combination of A. chroococcum and compost enhanced number and weight of earheads of wheat. Sharma (2008) reported that inoculation of biofertilizers by root dipping in 1 g Azotobacter + 1 ml Azospirillum + 1 ml PSB each mixed in 1 liter water + soil application of each @ 525 g or ml ha$^{-1}$ as basal recorded significantly higher grain and straw yield of wheat and N, P and K uptake over other treatments and control. Hassanein and Gomaa (2001) reported that the best results for plant height, number of tillers per plant, number of spikes per plant, weight of spikes per plant, as well as grain, straw and biological yields per plant were observed when biofertilized with phosphate-dissolving bacterium and treated with 15.5 kg P feddan$^{-1}$. [1 feddan = 0.42 ha]. Application of vermicompost in combination with BGA biofertilizer brought about a significant increase in nitrogen activity while Azotobacter + BGA treatment gave the highest values of chlorophyll (Prasanna et al., 2008).

**Green manuring + FYM**

**Rice**

Dhiman et al. (1999) studied the effects of organic farming (green manuring and FYM at 20 t ha$^{-1}$) and chemical fertilizers on scented rice (Basmati 370 and Taraori basmati), and found that rice quality was not affected by sources of nutrients. Milling, hulling and elongation ratio were greater in Basmati 370 and kernel length after cooking was higher in Taraori basmati. Green manuring of Sesbania rostrata (SR) with 5 t FYM (212 kg N ha$^{-1}$) was found most promising. FYM + SR resulted in significantly higher grain yield than even 180 kg N ha$^{-1}$ (Bishit et al., 2006).

**Wheat**

Nahar et al. (1996) observed that application of ipilipil (Leucaena leucocephala) leaves as green manure and cattle manure during the previous rice crop increased wheat yield to 1.98 and 2.2 t ha$^{-1}$, respectively. Dwivedi and Thakur (2000) found that the effect of residual organic manuring on the yield of wheat under rice-wheat cropping system. Biogas-slurry recorded wheat grain yield of 39.9–42.0 q ha$^{-1}$, rice-straw incorporation 36.9–39.0 q ha$^{-1}$, green manure 32.6–33.8 q ha$^{-1}$ and no organic manure 31.2–32.2 q ha$^{-1}$. Singh et al. (1995) revealed that application of 10 t FYM ha$^{-1}$ yielded significantly higher grain and straw yields of wheat over 5 t ha$^{-1}$ and control. Mehra and Singh (2007) reported that the combination of FYM, green manure, crop residue and biofertilizer (Azotobacter) with inorganic sources resulted in highest plant height (98 cm), no of tillers m$^{-2}$ (349), grain yield (41.36 q ha$^{-1}$) and straw yield (82.32 q ha$^{-1}$) of wheat and also highest N (144.99 kg ha$^{-1}$), P (36.40 kg ha$^{-1}$) and K (145.40 kg ha$^{-1}$) uptake by wheat. Singh et al. (2004) evaluated seven treatments, FYM comprised of various combinations of green manure (GM; Sesbania cannabina L.); wheat straw (WS), farmyard manure (FYM), and urea on yields and yield trends; P and K balance; and soil fertility in a rice–wheat experiment (1988–2000) on a loamy sand in Punjab, India. Organic materials applied to rice had no residual effect on wheat yields except FYM, which increased yield and by about 6% compared with urea alone. Wheat yields remained unchanged. Soil C as increased with the application of WS, FYM and GM. Potassium balance was highly negative. Although the causes of yield decline are unknown, inadequate K applications and changes in the climatic parameters are possible reasons.

**Green manuring + FYM + Biofertilizers**

**Rice**

According to Singh et al. (1988), application of FYM, Eichhornia and Azolla compost produced lower grain and straw yields and fewer panicles than 60 kg N ha$^{-1}$ as urea in 1983, but during 1984 all these treatments showed response equal to that of 60 kg N ha$^{-1}$ as urea. This may suggest a good potential of using the organic materials as alternative nutrient sources for rice crop under the long-term basis.

Jeyabal et al. (1999) observed that application of either FYM or enriched FYM combined with Azospirillum plus phosphobacteria (biofertilizers) gave 17.2 to 23.4% higher grain yield of rice than application of nutrients through inorganic fertilizers. Dixit and Gupta (2000) observed that application of farmyard manure at 10 t ha$^{-1}$ and blue green algae (BGA) (Cyanobacteria) inoculation either alone or in combination, increased the economic yield. The average increase in the grain yield due to BGA was 0.24 t ha$^{-1}$ (7.5%), while combined use of farmyard manure and BGA showed the increase of 0.60 t ha$^{-1}$ (19.2%).
Dixit and Gupta (2000) also pointed out that content and uptake of N, P and K showed increasing trends as a result of application of FYM, and blue green algae inoculation either alone or in combination.

Shanmugam and Veeraputhran (2001) revealed that application of either green manure (Sesbania aculeata at 6.25 t ha$^{-1}$) or farmyard manure (FYM) at 12.5 t ha$^{-1}$ combined with Azospirillum (2 kg ha$^{-1}$) significantly increased the growth attributes of rice. Subramanian and Rangarajan (1990) reported that combined application of green leaf manure (Azadirachta indica), FYM, cow dung slurry and Azospirillum brasilense gave the higher grain yield on previous organically than on inorganically fertilized plots.

Quyen and Sharma (2003) reported that application of FYM + SGM + BGA resulted in more N and P uptake of rice than FYM. Highest N uptake resulted when FYM + SGM + BGA + PSB were applied together, which was significantly superior to all combinations of inorganic and organic treatments. However, a combination of FYM + SGM + SGM + BGA + PSB significantly increased the P uptake by grain, straw and grain + straw over the combinations of FYM, SGM and BGA, whereas Sesbania green manure resulted in N and P uptake similar to 120 kg N+13 kg P +17 kg K ha$^{-1}$ and 120 kg N + 26 kg P +34 kg ha$^{-1}$ respectively. Total N and P uptake by rice crop with sesbania green manure were significantly more than that observed with FYM. Inoculation of BGA with FYM or SGM had no significant effect on total N uptake of rice, however when FYM+SGM+BGA were applied together they resulted in more N and P uptake of rice than FYM, SGM+FYM+BGA. Higher N uptake resulted when FYM+SGM+BGA were applied together, which was significantly superior to all combination of inorganic and organic treatments. However, a combination of FYM + SGM + SGM + BGA + PSB significantly increased the P uptake by grain, straw and grain + straw over other combinations of FYM, SGM and BGA except FYM+SGM+BGA. The effect of FYM, SGM and FYM + BGA on K uptake by grain, straw and grain + straw was increased.

Duxbury and Gupta (2000) reported that higher number of tillers, number of total spikelets per panicle, test weight, grain and straw yields, larger panicles and lesser unfilled spikelets in both years were recorded with application of Azolla along with 100% RDN. This was on par with the application of Azospirillum and BGA with 100% RDN. All the yield components, grain and straw yields of rice due to inoculation of any one of the biofertilizers along with 80% RDN were statistically similar to that of 100% RDN alone without any biofertilizer inoculation, indicating a saving of 20% RDN (24 kg N/ha) due to application of any one of the 3 biofertilizers.

Subashini et al. (2007) conducted an experiment and the results proved that there was a gradual increase in the efficiency of biofertilizer and its compatibility with inorganic fertilizers. Significant difference in the soil fertility status (available N, P and K) and the soil biota has increased in the plots treated with the biologicals in the later stage (the third season).

Kumar et al. (2007) reported that approximately 50% of recommended dose of inorganic fertilizers could be saved by using 20 t ha$^{-1}$ of farmyard manure (FYM) + 10 kg ha$^{-1}$ of BGA [blue green algae or cyanobacteria]. Supply of a portion of P and K along with secondary and micronutrients required by crops could help offset the negative nutrient balance and slow down nutrient depletion processes. Application of organic manures improved the physical, chemical and biological properties of soil.

Sharma (2006) reported that FYM + biofertilizers improved all the parameters of soil fertility over FYM alone as well over green manuring alone.

Kumar et. al. (2007) reported that the direct and residual application of green manure increased the yield of hybrid rice by up to 1240 kg/ha (42.61%) during the 1st year and 1275 kg/ha (45.94%) during the 2nd year. The highest grain yield of hybrid rice (9300 and 8670 kg/ha during 1st and 2nd year, respectively) was recorded for 150% NPK + green manure + biofertilizer. The increase in the yield of rice due to biofertilizer application ranged from 202 to 422 kg/ha during the 1st year, and from 290 to 388 kg/ha during the 2nd year. The greatest total removal of NPK (405.5 kg/ha and 394 kg/ha on the 1st and 2nd year in hybrid rice was registered for 150% NPK + green manure + biofertilizer. The increase in nutrient use efficiency due to green manure application was greater in the control and lower at higher rates of applied fertilizers for rice (0.7-43.9 %, with a mean value of 17.4%, on the 1st year, and 10.68-44.36%, with a mean value of 16.61%, on the 2nd year) The percent increase in nutrient use efficiency due to biofertilizer application on the 1st and 2nd year reached 6.5 and 8.16% in rice.
Wheat

Sushila and Giri (2000) reported that application of FYM and *Azotobacter* proved effective in enhancing the growth of wheat. Khosravi et al. (1998) observed a combination of *A. chroococcum* and compost enhanced the number and weight of earheads of wheat and they also observed a combination of *A. chroococcum* and compost enhanced number and weight of wheat heads.

Sharma (2006) studied the effect of different combinations of organic manures and biofertilizers in organic farming of rice-wheat and reported that application of 10 t ha\(^{-1}\) farmyard manure to rice increased grain yield over control by 1.21 t ha\(^{-1}\) in rice and 0.54 t ha\(^{-1}\) in wheat, whereas *Sesbania* green manuring increased grain yield over control by 1.43 t ha\(^{-1}\) in rice, 0.73 t ha\(^{-1}\) in wheat. The combinations of *Sesbania* green manuring + blue green algae and *Sesbania* green manuring + farmyard manure were more effective than farmyard manure and *Sesbania* green manuring alone and increased grain yield over control by 1.58 and 1.70 t ha\(^{-1}\) in rice and 0.80 and 0.83 t ha\(^{-1}\) in wheat, respectively. The combination of *Sesbania* green manuring + farmyard manure + blue green algae was still better and increased grain yield over control by 1.94 t ha\(^{-1}\) in rice and 1.02 t ha\(^{-1}\) in wheat. Similarly application of farmyard manure, *Leucaena* green leaf manuring, *Leucaena* green leaf manuring + *Azotobacter*, *Leucaena* green leaf manuring + FYM and *Leucaena* green leaf manuring + FYM + *Azotobacter* increased grain yield over control by 1.09, 1.10, 1.98 and 2.15 t ha\(^{-1}\) respectively in rice and by 0.28, 1.24, 1.26, 1.32 and 1.37 t ha\(^{-1}\) respectively in wheat. He also reported that application of organic manures and biofertilizers were more effective when applied to wheat. However, the potential yield of both rice and wheat was obtained when combination of farmyard manure + green manuring + biofertilizers was applied to both rice and wheat. Application of farmyard manure to both rice and wheat was significantly superior to farmyard manure only to wheat, which, in turn, was significantly superior to farmyard manure only to rice for increasing organic C, total N, available P and available K in soil. Similar results were obtained in case of green manuring for increasing organic C, total N and available P but available K remained same whether green manure was applied to rice or wheat or both. Advantage of biofertilizers with green manure or with green manure + farmyard manure was not reflected in any parameter of soil fertility. On the other hand, farmyard manure + green manuring improved all the parameters of soil fertility over farmyard manure alone as well as over green manuring alone.

Chakraborty et al. (2006) reported that compaction (reflected in bulk density values) was evidenced in sub-surface (0.15-0.30 m) layer in all treatments at rice harvest, minimum being under green leaf manuring + farmyard manure. Though the restoration of the bulk density was observed after wheat crop, overall minimum variation of the same took place with the application of green leaf manuring + farmyard manure + *Azotobacter* The optimum compaction of soil under these treatments was also reflected in \(K\_{sat}\) values (1.9-2.0 cm hr\(^{-1}\)). Total porosity did not show much variation over time, though maximum micropores were reported with the application of green leaf manuring + farmyard manure + *Azotobacter* in both surface (0.35-0.39 mg m\(^{-2}\)) and subsurface (0.29-0.36 Mg m\(^{-2}\)) soil. The final infiltration capacity of soil was also quite higher with green leaf manuring + farmyard manure + *Azotobacter* Effect of organic manures in aggregation of soil could not be seen after rice, but after wheat, better aggregation was recorded with green leaf manuring + farmyard manure + *Azotobacter* Overall, substitution of chemical fertilizers with organics showed better physical health of soil under rice-wheat system with a compromise in yield of 0.3 to 1.1 Mg ha\(^{-1}\) as compared to full fertilizer treatments in the specific soil and agroclimatic conditions of the study area.

Jat and Maitry (2006) reported that seed inoculation with PSB had significant positive effect on wheat yields, net return (Rs. 31336/ha) and B:C ratio (3.18) as compared to no inoculation. Fodder yield and economics of maize was not influenced significantly due to herbicides applied in preceding wheat crop.

Jarak et al. (2006) reported that depending on the cultivar and type of biofertilizers treatment, the increase of yield was 8-11%. Inoculation and nitrogen fertilizers contributed to the increased number of actinomycetes and azotobacter with all three cultivars. Dehydrogenase activity significantly increased in inoculated variants with two cultivars (Pobeda and Bg Maksima).

Elmholt (2006) reported that there was a slight additional increase in grain and straw yields when a biofertilizer was applied along with N fertilizer. The biofertilizer materials were not as effective as N fertilizers in producing grain (4.02-4.09 Mg ha\(^{-1}\)) or straw (7.71-8.11 Mg ha\(^{-1}\)), although the Nitrobien + Phosphorien combination increased these parameters over the N-fertilizer control. The effect of the Nitrobien biofertilizer in increasing grain yields was equivalent to a urea application rate of about 13 kg N ha\(^{-1}\). Biofertilizer inoculations increased iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) concentrations in wheat tissue (at boot stage), but these higher levels did not influence
grain or straw yield. Kumar et al. (2007) reported that use of biofertilizers and biomix with 75 and 100% RDN improved the economics of system in terms of gross and net returns and benefit:cost ratio over absolute control, 75 and 100% RDN.

Singh et al. (2007) reported that the integrated use of inorganic fertilizer, biofertilizers and organics enhanced the growth and yield of wheat. Higher plant height and yield attributes were recorded in 50 kg N ha\(^{-1}\) + Azospirillum + FYM @ 5 t/ha, followed by 150 kg N/ha. Further, seed and stover yields of wheat enhanced significantly at higher levels of N and integrated use of organic and biofertilizers. However, the highest yield attributes were recorded at 150 kg N/ha. The uptake of total nitrogen by wheat was significantly higher at 150 kg N/ha than at 50 kg N/ha + Azospirillum + FYM @ 5 t/ha. Jat and Maitry (2006) reported that the grain yield of wheat at 75% recommended dose of NP along with the application of FYM @ 10 t/ha and inoculation of PSB resulted in significantly higher yield even over the 100% recommended dose of NP.

**WEED CONTROL IN ORGANIC FARMING**

Compared to conventional farmers, the organic farmers use more of mechanical cultivation of row crops to reduce the weed menace. Different strategies are adopted to prevent weeds from competing with the crops for nutrients and water. The main weed control strategies used in organic farming is often combine cultural or husbandry techniques with direct mechanical and thermal methods (Lampkin, 1994; Stockdale et al., 2001). Mechanical and thermal intervention includes ridging – up spaced row crops, inter-row cultivation in root crops and cereals, post-emergence harrowing in cereal crops and heat treatment of weeds (infra-red or direct flaming) prior to crop emergence and in between rows. Weed control through crop rotation is more likely to be successful when the growth habit and characteristics of a crop contrast with those of the previous crop and predominant problem weeds. Diverse crop rotations are effective in reducing weed seedbank and preventing highly adapted weeds such as black grass, wild oats and volunteer crops from becoming dominant (Karnel et al., 1994; Lampkin, 1994).

The following methods can limit the germination of weed seeds:

(a) Using cover crops: Cover crops not only add organic matter into the soil but also shade out “weeds”. Due to this weeds do not get enough sunlight for the process of photosynthesis and become unable to reach maturity and set seeds.

(b) Pre-irrigating the fields to germinate weed seeds, and then ploughing them before they mature to reduce weed seeds in the soil.

(c) Using drip irrigation whenever possible to distribute water only around the plant line. This technique not only conserves water, but also limits water availability to weeds in the field.

(d) Crop rotation

(e) Biological control of weeds: By using biologically derived chemicals or by using insects that prevent growth of weeds.

**PEST MANAGEMENT IN ORGANIC FARMING**

The control of insects, pests ad pathogens is one of the most challenging jobs in organic farming. Non-chemical, biological pest and disease management is encouraged in organic farming. Lampkin (1994) stated that pests are generally not a significant problem in organic system, since healthy plants living in good soil with balanced nutrition are better able to resist pest and disease attack. Bezdicke and Power (1984) and Culliney and Pimentel (1986) supported this view.

Several methods are used for determining the pest population. Pheromone trap is one such tool, which is used for monitoring pests. Sex pheromones are bio-chemicals released usually by female insects as a means of chemical communication to attract males for mating. They are highly specific and are perceived by the males of the same species only. The synthetic phenomones are now in use for luring a variety of lepidopterous pests in small entrapments popularly called “pheromone traps”. These traps are effectively used in cotton, rice, vegetable and many other crops. Two traps per acre are often sufficient for the pest population. Pheromones are also exploited for mass trapping of certain pests particularly yellow stem borer in rice. Usually, ten traps per acre are used to mass trap the moths to reduce their population. Of late, pheromones are also used for disruption of mating cycle. Small bits of rope impregnated with pheromones are strewn for dispensing this chemical in the field. The crop environment pervaded by pheromone confuses the females to the extent that their mating get disrupted inspite of the fact that males are there in the field. The unmated females are rendered incapable of laying the eggs. Pheromones can be effectively used in organic farming.
Commercial production of biopesticides containing different bacteria, fungi and viruses has been undertaken to control certain insects. Spraying of *Bacillus thuringiensis*, a bacterium has successfully killed several lepidopteran insects. Another strategy could be to use beneficial insects like lady bugs, which feeds on aphids to control harmful pests. Some of the plant diseases that can be controlled by antagonistic fungi and bacteria are as follows: Rice seeds treated with *Pseudomonas aeruginosa* and *P. putida* reduced sheath blight infection (*Rhizoctonia solani*) in rice by 65-72 per cent in comparison to untreated check. *P. fluorescens* was also found effective against banded leaf and sheath blight fungus (*R. solani* f. sp. sasakii). *Trichoderma harzianum* as fungal antagonist proved effective against *Macrophomina phaseolina* (charcoal rot) in several plant species. *Trichoderma harzianum* and *Pseudomonas fluorescens* effectively suppressed mycelial growth, sclerotial production and germination of *Rhizoctonia solani* causing root rot of wheat. *Chaetomium globosum* Kunze Fr. has been identified as a potential bio-control agent of spot blotch of wheat caused by *Spechslera sorokiniana*.

Many botanicals have the potential to control pests and diseases of plants. Extracts of neem custard apple and callophyllum (undui) seed can control a wide range of insects, bacteria and fungi. Harmful insect-pests can also be controlled by releasing appropriate bio-control agents in the field.

**Conclusion**

The common organic amendments used in rice and wheat are Farm Yard Manure, Vermicompost, green manuring of *Sesbania, Gliricidia* and green leaf manuring of *Leucaena*, biofertilizers like Blue Green Algae, *Azolla, Azospirillum* and *Azotobacter* etc. Use of these different organic amendments in combinations and in a cumulative manner can meet the nutrient requirement of organic rice and wheat in rice-wheat cropping system. Organic farming enhances soil organic carbon, available phosphorus content and microbial population / enzymatic activity of soil thus making it sustainable for organic crop production. The main weed control strategies used in organic farming of rice-wheat cropping system is often combine cultural or husbandry techniques with direct mechanical and thermal methods. Pests are generally not a significant problem in organic system, since healthy plants living in good soil with balanced nutrition are better able to resist pest and disease attack. Commercial production of biopesticides containing different bacteria, fungi and viruses has been undertaken to control certain insects, pests & diseases. Rice seeds treated with *Pseudomonas aeruginosa* and *P. putida* reduced sheath blight infection (*Rhizoctonia solani*) in rice. *Chaetomium globosum* Kunze Fr. has been identified as a potential bio-control agent of spot blotch of wheat caused by *Spechslera sorokiniana*. Extracts of neem, callotropis, dhatura, Leptadenia, custard apple and callophyllum (undui) seed etc can control a wide range of insects, bacteria and fungi. Owing to positive influence of organic components in rice-wheat cropping system, it is therefore, be assumed that those farmers who adopted organic management practices found a way to improve the quality of their soil, or at least stemmed the deterioration. The system becomes long term productive by protecting soils and enhancing their fertility ensuring productive capacity for future generations.

**References**


