ASSESSMENT OF SOIL QUALITY PARAMETERS FOR SUSTAINABLE PRODUCTION IN RICE-WHEAT CROPPING SYSTEM

By

A. VELMURUGAN

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Approved by :

Chairman : (Dr. P.K. Chhonkar)

Members : (Dr. Dhyan Singh)

(Dr. G.C. Srivastava)

(Dr. A.K. Singh)

(Dr. P.K. Aggarwal)

Prof. P.K. Chhonkar
Ph.D., F.I.S.S.S., F.A.A.S.
Head.

Division of Soil Science and Agricultural Chemistry
Indian Agricultural Research Institute
New Delhi-110012

CERTIFICATE

This is to certify that the thesis entitled "**Assessment of soil quality parameters for sustainable production in rice-wheat cropping system**", submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Soil Science and Agricultural Chemistry** of the Post Graduate School, Indian Agricultural Research Institute, New Delhi, embodies the result of a *bona fide* research work carried out by **Mr. A. Velmurugan,** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

The assistance and help received by him during the course of investigation has been duly acknowledged.

P.K. Chhonkar 3.12.2000
(P.K. CHHONKAR)
Chairman
Advisory Committee

Place : New Delhi

Date : 3.12.2000

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Place : New Delhi

Date :

(A. VELMURUGAN)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

The total area under rice-wheat cropping system in India is estimated at about 10 Mha and it accounts for about one-third of the foodgrain production (Kar *et al.*, 1997). Further, rice-wheat system is expected to play an important role in future in producing food grains for increasing population. But the future production gains must come from more intensive land use practices because average arable land per capita in India which was 0.199 ha in 1990 and is estimated to fall further to 0.129 ha by 2010 and 0.085 ha by 2030.

Modern agricultural production practices have emphasized the widespread use of fertilizers overlooking use of organic manures. The continuous use of fertilizers at high levels over a prolonged period, discarding the use of organic manures and crop residues may adversely affect the sustainability of rice-wheat system (Kanwar, 1994). This is so. because growing crops under intensive farming as in the case of rice and wheat in the rice-wheat cropping system, puts an enormous strain on the two basic natural resources *i.e.*, soil and water.

The challenge of sustainability is to continuously enhance productivity and maintain it in relation to the demands expected from a production system. That is why, although rice-wheat system is in practice for more than 1000 years in India and China, the pressure on the system is discernible only after the intensification period of last three decades (Velayutham, 1997). Hence, concern has been expressed about rice-wheat system which fatigued the soils causing declining crop and factor productivity. Further, evidences show that grain yields under rice-wheat cropping system have either plateauned or registering a declining trend (Virmani, 1994).

Crop yield alone is an incomplete measure of agricultural system productivity. Soil quality, which can represent system productivity (Yakovchenko *et al.*, 1996), is defined as the capacity of the soil to function within ecosystem boundaries, maintain environmental quality, and promote plant, animal and human health (Doran and Parkin, 1994). An assessment of soil quality that includes soil biological, chemical and physical properties can provide valuable information for determining the sustainability of land management (Doran *et al.*, 1994).

Maintaining the sustainability of rice-wheat cropping system without degradation of the natural resource base has become very important. There should be an integrated method to monitor the sustainability of the production system. Hence, the present investigation was planned with the following objectives :

1. Assessment of soil quality parameters in rice-wheat cropping system.
2. To relate the observed soil quality parameters with the yield of rice and wheat.
3. Development of indices for soil quality in relation to sustainability of rice-wheat cropping system.

REVIEW

Rice-Wheat is the major cropping system in India, which helped tremendously to achieve self sufficiency in foodgrains. However, due to intensive cropping and faulty management pactices, in recent years the sustainability of the system has come under threat. Further, rice-wheat system exhaust the soil, affecting the soil quality. Soil quality can be used as a measure of sustainability of the rice-wheat cropping system. An attempt has been made to review these under the following headings;

2.1 Importance of rice-wheat cropping system

2.2 Effect of rice-wheat cropping system on soil characteristics

2.3 Effect of organic manures on soil characteristics and yield

2.4 Soil quality

2.5 Sustainability

2.1 IMPORTANCE OF RICE-WHEAT CROPPING SYSTEM

Rice-Wheat cropping system (RWCS) gained prominence from the mid 1960's with the introduction of short duration and high yielding varieties of rice and wheat. During the last three decades, the RWCS in India has significantly contributed towards enhancing the food grain production and achieving the food self-sufficiency and food security.

The rainfall distribution pattern and other climatic parameters, particularly the annual temperature cycle, are major factors in determining the adaptability of crops to a given region. Our monsoon type of rainfall causes water saturation of soil during the rainy season and making survival of crops other than rice difficult under such conditions. Rainy season temperatures are also fairly high. Therefore, the flat lands in humid regions, slowly permeable Vertisols and soils in the coastal regions have been traditionally used for growing rice. In some areas two to three crops of rice are taken in a sequence each year. Likewise, the low temperatures during December and January followed by warming up of weather in March/April in the northern and north-western India are eminently suited for cultivation of wheat. The availability of high yielding varieties of rice and energy to exploit ground water through shallow pumps together with remunerative support price for rice given by the Government of India, has stimulated the cultivation of rice in non-traditional rice areas like Punjab, Haryana and western Uttar Pradesh. Thus, the area under rice-wheat sequence has increased and it has become an important cropping system (Kar *et al.*, 1997).

The total area under rice-wheat system in India is estimated at about 10 Mha which accounts for about one-third of the food grain production of the country (Velayutham, 1997). It is more popular in the non-traditional rice growing states of Punjab, Haryana and Uttar Pradesh, and less in traditional rice growing states of Bihar and West Bengal. The overall productivity of this system is quite low which may be half or even less than half of its potential and it declines from west to east (Praduman Kumar *et al.*, 1998).

2.2. EFFECT OF RICE-WHEAT CROPPING SYSTEM ON SOIL CHARACTERISTICS

Rice and wheat have wide differences in the soil and agronomic requirements apart from climatic needs in terms of irradiance and temperature. Cultivation of rice-wheat cropping with the view to get more income and scant regard to the prudent use of the natural resource base affecting both soil and water quality brought about the fatigue in the sustainability of rice-wheat system in a span of less than ten years in non-traditional rice-wheat areas.

Chronological emergence of P,Zn.K,S and Mn deficiencies has been the bane of imbalanced fertilization. Even balanced application of NPK devoid of organic manures showing an utter disregard for soil care has been implicated with deterioration of physical, chemical and biological health (Rattan and Singh. 1997).

2.2.1 Physical properties

Physical edaphic requirements of lowland rice differ a great deal from that of wheat and other upland crops. Rice in major parts of rice-wheat tracts is raised as a transplanted crop and with its inbuilt aeration system thrives best in submerged or saturated soils at temperatures between 25°C and 37°C. Unlike rice, wheat seeds are put directly in the field which germinate and emerge as seedlings *in situ*. Therefore, a proper seed bed has to be prepared which is sufficiently moist, well aerated and provides a good seed-soil contact (Kar *et al.*, 1997). Hence the practice of RWCS has a marked influence on the soil physical properties.

2.2.1.1 Permeability

Puddling is the most important soil management practice in wetland rice. This operation breaks down soil structure and reduces the proportion of macropores and. thus, decreases hydraulic conductivity and permeability of soil (Sharma and De Datta, 1985). The depth of formation of least permeable layer by puddling and its formation mechanism depends upon soil texture. In coarse soils. reduction of permeability is caused by a clayey layer formed in the top 2 cm of puddled layer. In medium textured mineral soils, the reduction in percolation is caused by increased bulk density at the lower part of the puddled layer (Adachi, 1992). Destruction of aggregates by puddling decreases the transmission pores and hydraulic conductivity of the puddled layer. Sur *et al.* (1981) showed that pore water pressure in the soil below the puddled layer was negative even with water ponded at the surface.

2.2.1.2 Bulk density

Repeated puddling and compaction of the top layer results in the formation of a compact layer just below the depth of puddling. Sur *et al.* (1981) observed a layer of high bulk density and low permeability at 15-20 cm depth in a sandy loam soil after six years of rice-wheat rotation. Chenkual and Acharya (1990) also found that bulk density in the subsoil was higher under rice-wheat than under maize-wheat rotation. Patel *et al.* (1993) observed the maximum bulk density and minimum porosity after rice harvest. Addition of N fertilizer alone to rice-wheat increased the bulk density, but balanced NPK to rice-wheat counteracted the adverse effects of N on bulk density.

2.2.1.3 Temperature

Puddling may affect soil temperature indirectly by changing the duration and depths of water ponded at the surface and percolation rate (Sharma and De Datta, 1992). Since puddling favours ponding by reducing permeability, it would tend to keep the soil cooler by ponding more water than when water infiltrates rapidly. At the same time, water percolating downward may carry the heat to lower layers and keep the surface layers cooler.

2.2.1.4 Aeration

In puddled and submerged soil the rate of oxygen diffusion is negligibly low and remains mostly less than 5 μg cm^{-2} min^{-1} (Kumar *et al.*, 1992). Rice plants with inbuilt plant aeration mechanism, however, can grow well even at this low oxygen diffusion rate. But for most other plants a rate less than 30 μg cm^{-2} min^{-1} becomes limiting (Letey and Stolzy, 1964). A healthy range of redox potential can be maintained in rice rhizosphere by maintaining a minimum percolation rate. Soil compaction also helps in raising the redox potential of submerged soil (Kar *et al.*, 1976). Wheat productivity was affected more adversely by poor soil aeration rather than the restricted root growth due to subsoil compaction, provided nutrients were not limiting in rice soils (Lavbhushan and Sharma, 1999).

2.2.1.5 Tilth

Provision of proper seedbed for germination of wheat seeds requires the creation of appropriate tilth by ploughing, cultivating and pulverizing the top soil. Similarly any root restricting layers in the subsoil should be broken to promote deeper rooting. Puddling of soil for rice transplantation increases microporosity of soil and retention of water at a given tension. Consequently the soil permeability and post infiltration drainage get reduced and the soil remains wet for longer periods. If the soil is not loosened, the crop following rice is likely to suffer from poor soil aeration following heavy rain and/or irrigation (Kar *et al.*, 1997).

2.2.1.6 Percolation rates

Reduction of percolation rates through puddling is intended to reduce deep drainage losses of water. But it is usually held that some downward movement of water is necessary to wash down certain toxic substances produced under submerged soil conditions (Miang-Hua, 1981). Humphery *et al.* (1992) suggested that in areas threatened by rising water-table, percolation rates exceeding 3 mm/day may be ecologically unacceptable. Also, on low organic matter (10 to 30 g/kg) soils of Australia, rice yield did not exhibit any relation with infiltration rates. Sharma and De Datta (1992) reported similar observations for tropical soil having organic matter less than 50 g/kg.

Rice and wheat have wide differences in the soil and agronomic requirements apart from climatic needs. Puddling favours rice growth but it offers a very non-conducive soil physical environment for the following wheat crop (Prihar *et al.*, 1985).

2.2.2 pH

Flooding the soil increased the pH of acid soils, decreased the pH of alkali soils and kept the pH around neutral point (Ponnamperuma, 1972). Sarkar *et al.* (1988) reported changes in soil pH following straw incorporation after wheat crop. There was slight increase in pH due to increase in ammoniacal nitrogen in soil upon application of urea but subsequently, the pH decreased due to production of organic acids from decomposition of organic matter. Flooding the soil, however, resulted in higher pH than saturation. Alam *et al.* (1986) observed decrease in soil pH with rice-wheat cropping due to application of low grade pyrites in calcareous saline sodic soil. Raman *et al.* (1992) reported a decline in soil pH from 8.39 to 7.9 in rice-wheat rotation.

On the contrary, Kumar and Yadav (1993) did not notice much change in soil pH under different NPK management after 12 years of rice-wheat cropping. Sood *et al.* (1994) also reported that at the end of the experiment with rice-wheat system from 1977 to 1989 there was no change in soil pH.

2.2.3 Organic carbon

The changes in soil organic carbon in rice-wheat cropping system have also been well catalogued. Kumar and Yadav (1993) concluded that higher levels of N and P application maintained organic carbon level of the soil. Nambiar (1994) reported that higher dose of NPK (150% of recommended dose) and addition of farmyard manure maintained the organic carbon level in the soils. Sood *et al.* (1994) reported that there was no change in organic carbon in rice-wheat system at the end of field trials from 1979 to 1989. Singh *et al.* (1999) after their 10 years of intensive cropping with rice-wheat in a Mollisol reported that the status of organic matter went down drastically except in the plots receiving single superphosphate and FYM.

2.2.4 Nitrogen

The mineralization of nitrogen from organic matter stops at ammonium forming stage in the absence of oxygen in waterlogged soil. Ammonium N is therefore the dominant form of nitrogen in waterlogged soils. On the contrary, mineraliztion of organic matter continues up to nitrate forming stage under aerobic conditions of wheat cultivation. Patil and Sarkar (1993) found that 95 per cent of added ^{15}N was immobilized in soil mixed with wheat straw within 7 days. Remineralization of immobilized fertilizer N was faster in light textured soil. Mineralization of soil-N was more upon addition of fertilizer-N. This attributes to turn over effect leading to loss of added N by immobilization and gain of non-tagged N by mineralization.

In the *Typic Hapludolls* of Pantnagar, ammoniacal-N increased up to 30-50 DAT of rice and decreased thereafter. On the other hand, at Palampur (*Typic Hapludalf*), ammoniacal-N in soil increased at the tillering stage of rice crop, decreased thereafter with a slight increase at the flowering stage. The ammoniacal-N content in soil at tillering stage had significant positive correlation with the yield and N-uptake by rice, thus suggesting the reliability of basing ammoniacal-N as an index of N availability in waterlogged soils (Prasad and Rokima, 1991).

Available N decreased under rice-wheat system even with high level of fertilizer N application. Bhandari *et al.* (1992) noticed reduction in available N in soil after 3 years of rice-wheat sequence at less than recommended levels of NPK treatment. Kumar and Yadav (1993) reported that with continuous rice-wheat cropping at Masodha, there was a significant decrease in available N in soil from the initial value and its magnitude increased with reduction of the level of fertilizer N.

Data obtained from Pantnagar (Bharadwaj and Omanwar, 1994) showed that there was an increase in soil available N under rice-wheat-cowpea cropping with NPK or NPK+FYM application but there was a decrease in case of control. Sood *et al.* (1994) also reported increase in available N under rice-wheat rotation. Swarup (1991) from his experiment in sodic soils with rice-wheat system reported that there was a distinct increase in the available N in soil profile because of higher levels of nutrient application.

Nitrogen is very much susceptible to loss by various pathways and has to be applied every year in a rice-wheat cropping system (Mohanty and Singh, 1997).

2.2.5 Phosphorus

Response to application of P in most of the wetland rice soils under submergence has been marginal even though the soil test values show the deficiency range. The reason for lack of response has been attributed to increased availability of P due to reductant solubilization of Fe-P and hydrolytic solubilization of Al-P. On the other hand, response to P application by wheat crop has been reported widely (Mohanty and Singh, 1997). Increase in available P in wetland soils at wide pH range was mainly due to reduction of ferric-P to ferrous-P. Dash *et al.* (1982) reported that flooding converted a part of inorganic P into labile-P in soils.

Nad and Goswami (1984) observed that continuous application of P fertilizer to a rice-wheat cropping system for over 10 seasons resulted in an increase of Al-P and Fe-P fractions. Dhillon and Dev (1988) found that in Somana sandy loam soil of Punjab with rice-wheat cropping sequence, added superphosphate got converted mainly to Al-P, and to some extent to saloid-P with a little change in Fe-P. Saloid-P present originally in small amounts got exhausted by rice but increased with the following wheat crop. Al-P declined sharply after *kharif* rice and this decline was more in high P soils. Ca-P continued to decrease due to growing of the crop and the decline was more in rice-wheat rotation.

From long-term fertilizer experiment carried out at Pantnagar involving rice-wheat-cowpea cropping for 13 years, Agarwal *et al.* (1987) observed that graded dose of NPK fertilizers increased the available-P but Ca-P remained at original level. Al-P was found to be more important fraction contributed towards available P followed by reductant soluble P and saloid-P.

Availability of phosphorus under rice cultivation increased up to 10 days after transplanting at Pusa. up to 40 days at Pantnagar and decreased thereafter whereas at Palampur there was continuous increase in it upto flowering stage of the crop growth (Pande and Mohanty, 1986). The increase in availability of P was attributed to decrease in soil pH and accumulation of CO_2 at Pusa and Pantnagar where the soil reaction was alkaline and at Palampur due to reductant solubilization of Fe-P and hydrolytic solubilization of Al-P in acidic pH condition.

Bhandari *et al.* (1992) recorded decrease in available P in soils of Ludhiana after 3 years of rice-wheat sequence where no nutrient was applied. but there was distinct increase in it with the application of sub-optimal or optimal dose of NPK. Dhillon *et al.* (1993) reported increase in Olsen P over the initial value with continuous application of P in a 2-year rice-wheat cropping, whereas there was a drastic decrease in the available P status when no P was added. Similarly Kumar and Yadav (1993) observed an accumulation of available P in the soil under rice-wheat cropping for 12 years due to NPK application and a decrease in no-P treatment and control treatment where no fertilizer was added. Now it is well established that the application of phosphatic fertilizer in the rice-wheat cropping system is more beneficial for wheat crop.

2.2.6 Potassium

Alluvial soils in northern plains are often rich in potassium due to the presence of mica and illite clay minerals in soil and generally do not respond to its application. But with intensive cultivation of rice-wheat system, response to K is increasing. Bharadwaj *et al.* (1994) observed that after 4 years of rice-wheat cropping. the added K was transformed into water soluble, exchangeable and non-exchangeable fractions. Potassium release in water soluble, exchangeable and non-exchangeable K with application of FYM or blue green algae or both over chemical fertilizer, were in the range of 2-3 ppm, 2.5-5.3 ppm and 3-33 ppm, respectively.

Availability of potassium in waterlogged soils under rice cultivation has been reported to increase due to secondary effect of reduction of soil and displacement by the action of water through hydration and hydrolysis (Mohanty and Patnaik, 1977). Changes in available K with different levels of N, P and K was studied by Kumar and Yadav (1993). After 12 years of continuous cropping of rice-wheat with different levels of N,P and K, it was observed that there was a decrease in available K in soil over the initial value in the treatments which did not receive K.

Data obtained by Bharadwaj *et al.* (1994) show a drastic decrease in available K in control plots and significant decrease in all fertilizer treatments except when N was supplied through FYM with continuous rice-wheat cropping for 3 years. These data suggest that there is a necessity of increasing level of K application to soils for sustaining available K status. Nambiar (1994) observed decrease in available K status in the soils with long-term fertilizer experiment under different cropping systems, particularly in the treatments which did not receive K fertilizer over 15-16 years but there was build-up of available K in the treatments receiving NPK fertilizer. Maximum depletion was with NP treatment. Similar observation was also made by Agarwal *et al.* (1993) with respect to available K and HNO_3-soluble K.

2.2.7 Micronutrients

Prasad *et al.* (1989) and Prasad and Umar (1990) noted a decrease in available Zn status in the soil in the succeeding wheat crop in rice-wheat cropping system in calcareous soil. In Zn deficient soil, lower rate (5 kg/ha) of Zn got transformed to unavailable form and was not available to the next wheat crop, but at higher rate (10 kg/ha) wheat yield was more (Chhibba *et al.*, 1989).

Gupta and Mehla (1993) reported decrease in available Zn in soil from initial value due to continuous rice-wheat cropping for 3 years on Typic Ustochrept of Hisar. The magnitude of decrease was more with increased level of nutrient application. Continuous cropping of rice-wheat-cowpea decreased DTPA extractable Zn and Cu in fertilized as well as unfertilized plots (Bharadwaj and Omanwar, 1994).

Marked increase in available Fe was noticed (Nambiar, 1994) over the years in comparison to their initial values under intensive cropping on *Ustochrept*, but there was a decrease in available Fe and Mn in *Hapludoll* of Pantnagar due to continuous cropping of rice-wheat-cowpea with or without fertilizer application (Bharadwaj and Omanwar, 1994). In rice-wheat rotations, Raman *et al.* (1992) reported an increase in available Mn, DTPA extractable Zn and Fe. Sood *et al.* (1994) from their field trials with rice-wheat system from 1977 to 1989 reported that the soil contained sufficient levels of Fe, Cu, Mn and Zn after 11 years of the experiment, however, Mn decreased with increasing levels of N, P or K.

Gupta and Mehla (1993) reported decrease in available Fe and Mn in soil from the initial values after 3 years of rice-wheat rotation. The magnitude of decrease in available Fe was more in control and it decreased with increased application of nutrients. On the contrary, the reverse trend was noticed in the case of available Mn in soil. It is important to note that continuous cultivation of rice-wheat depletes the available zinc, sulphur and other secondary nutrients in the soil. When these fall below the critical levels, external sources of these elements are absolutely essential to raise the available status of these elements to maintain the productivity of these soils.

2.2.8 Biological properties

Rice-wheat cropping system influences the biological properties of soil in various ways. Because of its wide difference in physical edaphic requirements, exhaustive nature and characters of the crop itself, the biological properties also varies.

2.2.8.1 Microbial biomass

The soil microbial biomass is the principle component of the decomposer subsystem regulating nutrient cycling, energy flow and ultimately plant and ecosystem productivity. However, it is not static. The temporal variability of the soil microbial biomass is an important component of its turnover, and thus contributes to patterns of soil nutrient release and mineralization (Wardle, 1998).

The soil biomass increased during the growth of a wheat crop and then decreased to an approximately constant amount. The biomass was significantly greater where the soil had been direct-drilled than where it had been ploughed. In spring and summer, the biomass was about three times as great as in the autumn and winter (Lynch and Panting, 1980). In a wheat field, the active but not the total microbial biomass was significantly stimulated by the growth of the crop (Van de and Verstracte, 1987).

Increasing cropping intensity in various wheat-fallow sequences resulted in greater soil microbial biomass after 30 years (Campbell *et al.*, 1991). Continuous wheat and wheat-pea sequences had greater soil microbial biomass than wheat-fallow after 58 years (Collins *et al.*, 1992).

2.2.8.2 Dehydrogenase activity (DHA)

Chendrayan *et al.* (1980) observed several fold increase in DHA under flooding. It was highest in laterite soils. Soil DHA was correlated significantly and positively with clay and negatively with silt under flooded conditions.

Lalita Batra (1998) studied the DHA of deteriorated sodic soils under rice and sorghum based cropping sequence. The results showed that the DHA was greater under rice based than under sorghum based cropping sequence. Within rice-based, rice-berseem showed the maximum DHA than other sequences. After 3 years of cropping, a 73 per cent increase in DHA was observed with the addition of gypsum as compared with no-gypsum treatment. A progressive increase in DHA was observed up to 90 days after rice transplanting.

2.2.8.3 Respiration

Measurement of soil respiration is widely accepted as a useful approach for studying the biological activities and carbon and energy flow with respect to detritus ecology (Singh and Chandrashekhar, 1986).

However, under saturated or waterlogged conditions the soil respiration rate decreases. Carbon dioxide output is positively affected by soil water content for similar temperatures (Kucera and Kirkham, 1971). Further it is shown that temperature exerts a decisive influence on CO_2 metabolism of the soil when there is sufficient water supply (Gupta and Singh, 1981). In a wheat-maize rotation, the seasonal pattern in total soil respiration indicated maximum CO_2 evolution rates during maize crop period followed by wheat, summer fallow and pre-winter periods (Singh and Chandra shekhar, 1986). The maximum soil respiration during the growing season of maize and wheat coincides with the period of maximum growth of both crops (Rochette *et al.*, 1991).

2.2.8.4 Respiration to microbial biomass ratio (specific respiratory activity)

The rate of CO_2 evolution from soil as a measure of respiratory activity of soil has been shown to depend upon environmental factors, including temperature and water content (Bunnel *et al.*, 1977), available C, and C/N ratio (McGill *et al.*, 1986; Parnas, 1975). With the increase in microbial biomass carbon, soil respiration (CO_2-evolved) increases. However, the increase in microbial biomass with higher levels of carbon consists of more dormant cells and hence, the specific respiratory activity (CO_2-C/BC) can be used as an indicator of such changes (Kukreja *et al.*, 1991). This reflects the overall activity or energy expenditure of the microbial biomass (Anderson and Domsh, 1985).

Ocio and Brookes (1990) reported that biomass of the sandy soil, whether amended with wheat straw or not, had a higher specific respiration rate than that in the clay soil. After their long-term field experiment, Kukreja *et al.* (1991) and Campbell *et al.* (1991) stated that application of farmyard manure increased the microbial biomass and the specific respiratory activity decreased with increasing amounts of microbial biomass in the soil. Campbell *et al.* (1992) reported that fertilizer had no effect on the specific respiratory activity. Reducing frequency in monoculture wheat systems increased specific respiratory activity.

2.3 EFFECT OF ORGANIC MANURES ON SOIL CHARACTERISTICS AND YIELD

The adoption of modern agricultural techniques has revolutionized food grain production bringing it up to levels to feed the fast growing population of the world. To achieve this, fertilizers have been the most commonly used sources for supplying nutrients to crop plants. However, in recent years there has been a tremendous renewal of interest in the old practice of organic and green manuring in order to maintain the sustainability of soil productivity as land is called upon to produce higher yields from a single crop and higher total yields under intensive cropping systems. The benefits of application of organic manures and green manure include increases in organic matter content and available plant nutrients and improvement in the microbiological and physical properties of the soil (Singh *et al.*, 1992).

2.3.1 Physical properties

Application of green manure decreased the bulk density of the soil and increased the aeration (Ventura and Watanabe, 1993). The decrease in soil bulk density on addition of FYM or GM in rice-wheat system is well documented (Bopari *et al.*. 1993; Nahar *et al.*, 1995; Aggarwal *et al.*, 1997). A 10-year field experiment on *Typic Chromusterts* in Karnataka, India, indicated that application of organic manures to meet 50% of N requirements along with 50% of NPK recorded significantly lower bulk density (Bellakki *et al.*, 1998).

2.3.2 Electrochemical properties

In an acid soil, Debnath and Hajra (1972) observed a significant increase in soil pH only during the first 30 days of incubation under aerobic conditions. In comparison with waterlogged situations, changes in soil pH with green manuring under upland conditions are less marked. Bajpai *et al.* (1980) observed that under aerobic soil conditions green manuring with *sesbania* reduced pH effectively during the initial 2-week incubation period in a loam soil (pH 7.2). However, in a saline sodic clay loam soil (pH 9.9) the effect of green manuring was observed only after 2 weeks.

Swarup (1991) observed decrease in pH of surface soil (0-0.15m) from 10.3 to 8.9 in the sodic soil due to continuous cropping in rice-wheat for four years without green-manuring and to 8.7 with green manuring. The organic source with fertilizers decreased the soil pH, EC at a faster rate than inorganic fertilizers alone in a partially reclaimed sodic soil with rice-wheat sequence (Alok Kumar and Yadav, 1995). Under waterlogged conditions, EC of soil solution increases with time, reaches a peak, and then decreases (Singh *et al.*, 1992).

2.3.3 Organic carbon

Green manuring in rice-wheat system for four years appreciably changed organic carbon content in the soil profile, with higher magnitude of increase in surface layer of sodic soil (Swarup, 1991). Similarly, Bhat *et al.* (1991) reported increase in organic carbon level of the soil with incorporation of wheat straw before rice and rice straw before wheat continuously for 7 years in a rice-wheat cropping system in *Ustochrepts* of Ludhiana. Under tropical conditions, judicious application of organic matter periodically is essential for improving and maintaining organic matter status of the soils.

Kukreja *et al.* (1991) reported after their long term field experiment that organic carbon content increased with increasing amounts of FYM application. It increased by 0.68% with the addition of 90 t/ha of FYM for 20 years. However, the organic carbon was generally less in treatments receiving inorganic N. Campbell *et al.* (1991) studied the effect of crop rotations and cultural practices and reported that generally fertilizer increased soil organic carbon in continuous wheat cropping but not in fallow-wheat or fallow-wheat-wheat rotations. With increasing frequency of cropping and with the inclusion of legumes as green manure in the rotation, soil organic carbon was found to increase.

2.3.4. Nitrogen

Kukreja *et al.* (1991) reported that the total and available N increased with the addition of increasing amounts of FYM, but these were less in treatments receiving inorganic N. The total N increased nearly in the same proportion as organic carbon. but the increase in available N was less. Addition of FYM (10 t/ha) in addition to 100 per cent NPK dose showed maximum increase of available N (Mandal *et al.*, 1991).

Residual effects on the grain yield, soil nitrogen and N uptake of rice after nine rice crops were found by Ventura and Watanabe (1993) with a continuous application of green manure (*Sesbania* spp.). Tiwari *et al.* (1995) reported that after 2 cycles of rice-wheat cropping soil N decreased in all the plots except in the green manured plots fertilized with 120 kg N/ha. The N content in rice soil increased sharply on *Sesbania* incorporation up to 20 days after transplanting and thereafter declined gradually.

2.3.5 Phosphorus

In waterlogged soils, green manuring increases availability of P through the mechanisms of reduction, chelation and favourable changes in soil pH (Singh *et al.*, 1992). Further. effect of green manuring in increasing the availability of P is more pronounced in strongly acidic and alkaline soils than in normal soils.

Prasad and Rokima (1991) in a study involving P application in combination with organic manure to rice-wheat system found that after 5 rotations most of the added P was transformed into organic-P and Ca-P and very little to water soluble-P, saloid-P, Al-P and Fe-P. Addition of FYM with fertilizer P enhanced the build-up of all forms of inorganic P. Al-P, Fe-P and saloid-P were the dominant forms that contributed most either directly or indirectly towards available P and its subsequent utilization by rice and wheat crops. Conjunctive application of green manure or farmyard manure further increased available-P status in the soil. However, Swarup (1991) found reduction in available P in the sodic soil with 4 years of rice-wheat cropping where no-P was applied, but there was an increase in the available P in the soil profile except top layer when green manure was applied with nitrogen.

2.3.6 Potassium

There was increase in availability of K in Vertisol with rice-wheat cropping due to application of organic manure (More, 1992). Bharadwaj and Omanwar (1994) reported increase in available K status in soil with increasing number of rice-wheat-cowpea cropping sequences even with control treatment, indicating thereby the role of legume crop in maintaining soil available K status for production.

Hargrove (1986) showed that increase in the available K due to green manuring in the surface layer was due to the recycling of K from the subsurface layer.

2.3.7 Biological properties

Application of organic manures to rice-wheat system not only improves the physical and chemical properties of soil but also the biological properties. It helps the soil to adjust itself to the varying needs of rice-wheat cropping system.

2.3.7.1 Microbial biomass

The size of soil microbial biomass is governed by various management practices such as crop rotation, cultivation, organic amendments, fertilization and crop residue management (McGill *et al.*, 1986).

Bolten *et al.* (1985) observed a 26.6% increase in microbial biomass with the continuous use of leguminous green manures over the application of chemical fertilizers. Kukreja *et al.* (1991) reported that the microbial biomass increased with increasing applications of farmyard manure and the biomass was more in treatments receiving inorganic N along with FYM.

Ghoshal and Singh (1994) indicated that FYM application to rice-wheat system increased the microbial biomass level per unit soil organic matter and caused a shift in organic matter equilibrium. Rao and Pathak (1996) reported that with the increase in EC and pH of soil the biomass carbon decreases. But the addition of green manure as amendment in alkali soil and leaching in saline soils the microbial biomass increased.

2.3.7.2 Dehydrogenase activity (DHA)

The DHA has been linked with the levels of readily available organic C substrates in the soil (Fraser *et al.*, 1988). The higher levels of DHA in the sandy loam soil may be the result of its higher organic C. Ladd and Paul (1973) reported increase in DHA with increasing organic matter content and microbial population of soil. Bolton *et al.* (1985) compared an organic system which used crop rotations and green manures with a conventional system without a green manure component and concluded that the DHA was higher in the organic system.

Kukraja *et al.* (1991) shown that the DHA increased with increasing amounts of FYM but the increase was not in the same proportion as in the case of microbial biomass. This indicated that a part of biomass was metabolically inactive.

Rao and Pathak (1996) reported an increase in DHA in saline and alkaline soils on addition of organic amendments.

2.3.7.3 Respiration

Soil respiration can be used as a measure of soil activity. However, all the microbial biomass in soil is not in active stage and with the increase in microbial biomass the dormant cells also increase. The term 'dormant' is based on the assumption that under field conditions energy limitations allow only small parts of the total potentially active population to be active at any given time. The majority exists as vegetative cells in a reduced state of metabolic activity (Gray and Williams, 1971). The difference between the 'dormant' and metabolically activated population is best exemplified by comparing the basal respiration of field soil samples with samples which are optimally carbon supplied. The latter shows a CO_2 output which is up to five times higher (Parkinson *et al.*, 1978; Sparling, 1981; Anderson and Domsch, 1985).

Buyonovsky *et al.* (1986) studied the soil respiration in a winter wheat ecosystem and reported that maximum soil respiration, presumably from decomposition activity on freshly incorporated residues, occurred during a 56-d period after harvest and accounted for 40% of the total amount of CO_2 evolved from soil. Rao and Pathak (1996) and Cooper and Warman (1997) observed an increase in respiration of soil where organic matter was added into soil.

2.3.7.4 Microbial biomass to total organic carbon ratio

The ratio of biomass-C to total organic C will increase if the input of organic matter to a soil is increased and decreases if the input is decreased. Constancy of the ratio is thus an indication of a system at a new equilibrium (Dalal and Mayer, 1986). The change in the proportion of organic matter in the microbial biomass provides a better index of organic matter alone. The index can be used as a sensitive parameter for assessing organic matter changes in management studies (Ghoshal and Singh, 1994).

Manuring practices have a direct influence on the C_{mic}-to-C_{org} relationship. Monoculture plots and crop rotation plots which had received organic manure amendments the previous year showed an increase in microbial carbon per unit soil organic carbon. This increase of the C_{mic}-to-C_{org} ratio over that of unamended soils was particularly marked in the monoculture system (Anderson and Domsh, 1989).

2.3.8 Yield

Gines *et al.* (1986) observed that rice yield obtained on incorporation of *S. rostrata* was comparable with that obtained under 105 kg N/ha. Sharma and Sharma (1993) observed that combined application of FYM to rice with 50% NPK produced statistically same yield as 100% NPK without FYM.

Further, 100% NPK with FYM gave statistically same yield as 150% NPK alone in the first year, but significantly higher in the next year.

Tiwari *et al.* (1995) reported that application of *S. rostrata* during summer and 120 kg N/ha to rice increased its yield from 2.3 to 5.8 t/ha during 1989-90 and 2.8 to 7.2 t/ha during 1990-91 compared with the control. Without fertilizer it increased the yield by 46%. Alok Kumar and Yadav (1995) reported from their long-term field experiments with rice-wheat cropping system that during the initial years of experiment 25-50% substitution of fertilizers through organic sources (FYM, GM, wheat straw) reduced the rice yield by 6.23% compared with 100% fertilizers alone. However, in the following years 25-50% N through FYM or GM along with 50-70% fertilizers to rice gave either equal or more yield compared with 100% NPK alone.

Raising of NPK level from 100 to 150% did not show any significant response in grain yield of rice in a long term trials (Mandal *et al.*, 1991). However, Mandal *et al.* (1984) observed positive response of wheat with increase in NPK. Increase in wheat yield due to carry over effect of green manure as well as N fertilization to rice crop was also reported in a rice-wheat system (Tiwari *et al.*, 1995).

2.4 SOIL QUALITY

As a result of continuous and intensive crop production, mechanization of agriculture, inefficient irrigation, reduction in recycling of organic materials and increased use of agrochemicals, the quality of many soils has declined significantly since cultivation was initiated. Hence, the term soil quality came to the forefront. The quality of soil is largely defined by soil function and represents a composite of its physical, chemical and biological properties.

2.4.1 Defining soil quality

Quality with respect to soil can be viewed in two ways. i.e., as inherent properties of soil and as the dynamic nature of soils as influenced by climate. and human use and management. With respect to inherent properties. a soil is a result of the factors of soil formation. The second view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared, and is currently the focal point for the term 'soil quality' (Larson and Pierce, 1991; Larson and Pierce, 1994).

Larson and Pierce (1991) defined soil quality as the physical. biological and chemical properties that provide a medium for plant growth. regulate and partition water flow in the environment, and serve as an environmental buffer in the formation, attenuation and degradation of environmentally hazardous compounds. Parr *et al.* (1992) stated that soil quality should serve as an indicator of change in both the soils' ability to produce optimum levels of safe and nutritious food, and its structural and biological integrity, which in turn is related to the status of certain degradative processes and to environmental and biological plant stress.

Doran and Parkin (1994) defined soil quality as the capacity of the soil to function within ecosystem boundaries, maintain environmental quality, and promote plant, animal and human health. Karlen *et al.* (1997) defined soil quality as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

2.4.2 Soil quality indicators

Soils have chemical, biological and physical properties that interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred form measuring changes in its attributes or attributes of the ecosystem, referred to as indicators (Seybold *et al.*, 1998). Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality, and human and animal health. They should also be used to assess the change in soil function within land use or ecosystem boundaries.

Arshad and Coen (1992) suggested that indicators should be sensitive enough to detect changes in soil as a result of anthropogenic degradation. Doran and Parkin (1994) have defined a set of specific criteria that indicators of soil quality must possess. They should encompass ecosystem processes and relate to process oirented modelling; integrate soil physical, chemical and biological properties and processes; be accessible to many users and applicable to field conditions; be sensitive to variations in management and climate; and where possible, be components of existing soil data bases. Also, indicators should be easily measured and measurements should be reproducible.

It would be unrealistic to use all ecosystem or soil attributes as indicators, so a minimum data set (MDS) consisting of a core set of attributes encompassing chemical, physical, and biological soil properties are selected for soil quality assessment (Larson and Pierce, 1991). The set of indicators used for assessing soil quality can vary from location to location depending on the kind of land or land use, soil function, and the soil forming factors (Arshad and Coen, 1992).

Doran and Parkin (1994) proposed a set of soil quality indicators which included physical, chemical and biological soil properties. Jordan *et al.* (1995) stated that soil microbial biomass C and enzyme assays seemed to be better potential indicators of cropping histories than other methods tested in the long-term plots. Soil respiration measurements have been the most widely used ones to monitor organic matter decomposition and biological activity. Rao and Pathak (1996) showed improved biological activity upon decomposition of *Sesbania* green manure in saline and alkali soils.

Yakovchenko *et al.* (1996) described the ratio of crop N uptake to mineralized N as determined by microbial respiration plus net mineralized N found over a growing season as a useful indicator of soil quality. Biological properties have received less emphasis than chemical and physical peoperties in characterizing soil quality because their effects are difficult to measure or predict (Parr *et al.*, 1992). Yakovchenko *et al.* (1996) proposed several indicators of soil biological properties, i.e., microbiological biomass content, microbial diversity and activity, enzyme activity, *etc.*

2.4.3 Assessment of soil quality

Soil quality can not be readily assessed directly by any single parameter, but instead must be evaluated as the function of several independent and/ or correlated chemical, physical and biological properties that may exist at different spatial or temporal scales (Parr *et al.*, 1992). Smith *et al.* (1993) suggested that soil quality can be determined by estimating the effects of interacting soil characteristics which define soil quality. The only decision to be made is whether the soil characteristic is an indication of good, average, or poor soil quality.

One way to integrate information obtained from multiple data set (MDS) measurements is to develop a soil quality index. Such an index could be used to provide early signs of soil degradation (Parr *et al.*, 1992). Granatstein and Bexdicek (1992) suggested the need for a soil quality index that reflects both the general potential for human use and unique biophysical conditions of a specific location.

Karlen *et al.* (1994) suggested four soil functions, *viz.*, accomodating water entry, facilitating water transfer and absorption, resisting surface degradation and supporting plant growth as being important for soil quality assessment. Larson and Pierce (1991) suggested a concept for quantifying soil quality by expressing soil quality (Q) as a function of measurable soil attributes referred to as soil qualities (qi): Q = f (q1..n), with the magnitude of Q being a function of the collective contribution of all qi values. They also measured the change in soil quality over time (dQ/dt) and proposed the use of minimum data set of measured soil properties and pedotransfer functions for assessing soil quality.

Singh *et al.* (1992) have developed a soil tilth index and is based on using five physical soil properties or indicators *viz.*, bulk density, cone index, aggregate size uniformity coefficient, organic matter, and plastic index. Smith *et al.* (1993) developed an approach (multiple indicator kriging procedure) that integrates an unlimited number of soil quality indicators, measured spatially, into an overall soil quality index, and then using that procedure to evaluate soil quality across landscapes. A kriging procedure is used to estimate index values at unsampled locations, which represent the probability that unknown values meet or do not meet the specified criteria for good soil quality. The result is a landscape map showing the probability of having good soil quality according to predetermined criteria. These maps can then be used for land use planning, and compared over time for changes in soil quality (Smith *et al.*. 1994).

Karlen and Stott (1994) developed a framework for quantifying soil quality using multi-objective analysis principles of systems engineering. They defined critical soil functions and potential chemical and physical indicators of those functions. For each indicator, a scoring function, and realistic baseline and threshold values are established. The system engineering approach to quantifying soil quality was tested in two long-term (10year) studies that attempts to show the effects of tillage and crop residue effects on soil quality ratings. The results showed that no-till management had an improved soil quality rating over plow and chisel till and double crop residue treatment had an improved soil quality rating over removal and normal residue treatments (Karlen *et al.*, 1994). This approach to quantifying soil quality is suggested as a starting point for the development of a soil quality index.

Halvorson *et al.* (1996) evaluated soil quality from the integration of six soil variables measured at 220 locations based on non-parametric geostatistics. They converted the continuous data values for each soil variable at each location to a binary variable indicator transform based on thresholds. The indicator transformed data for individual soil variables were then combined into a single integrative indicator of soil quality, termed a multiple varible indicator transform (MVIT). If MVIT criteria adequately reflect soil quality then the kriging can produce maps of the probability of a soil being of good or poor qulity.

2.5 SUSTAINABILITY

The principle of sustainability production according to Lynam and Herdt (1988) implies. 'a system with non-negative trend in measured output'. Using imbalanced production inputs, one may exploit the soil for an economically profitable harvest or output but in no case such profit should be borrowed from the future generations. In the event of increasing intensities of intensive cropping, one should not be concerned only with the harvest from the soil but also be more concerned about the extent to which the productive characteristics of soil are effective in limiting a higher production level.

2.5.1 Sustainability of rice-wheat cropping system

The rice-wheat cropping system, though very attractive in the short run, has turned out to be an unsustainable one because of over exploitation of the soil resource base coupled with unbalanced use of inputs. The unsustainability of rice-wheat cropping system has expressed itself in decling soil, crop and factor productivity; falling water tables in tube-well irrigated areas: development of secondary salinization and waterlogging in the canal irrigated areas; emergence of multi-nutrient deficiencies and increased incidence of pests and diseases (Rattan and Singh, 1997).

The production resource base for rice-wheat systems have been both shrinking and degrading under the pressure of increasing population and development needs (Singh, 1999). Productivity in some major agro-ecological systems has ceased to increase and in others has declined, raising concerns about long-term sustainability of such systems (Singh and Paroda, 1994).

Sustainability of rice-wheat cropping system in India, currently practised in about 9.5 Mha assumes significance because share of rice and wheat in total cereal is expected to increase from 80 per cent during 1990 to 85 per cent in 2020 A.D. (Paroda, 1996).

In intensive rice-production systems, there is evidence of stagnation or even decline in the yield frontier. Flinn and De Datta (1984) reported of yield stagnation or decline in both the wet and dry seasons in long-term experiments at IRRI and three other locations in Philippines.

Narang *et al.* (1990) conducted a field trial in 1986-88 with a rice-wheat cropping sequence and concluded that a total yield of about 15 t/ha (9.5 t paddy + 5.9 t wheat grain) is possible to obtain by growing rice at 44 hills/m^2 and wheat in rows 15 cm apart, applying NPK at 120 + 13 + 25 kg/ha with green manuring or 180 + 13 + 25 kg/ha without green manuring to rice and NPK at 180 + 39 + 75 kg/ha to wheat.

Nambiar (1995) has depicted the vulnerability of sustainability of rice-wheat cropping system through the data from long term fertilizer experiment in progress at Pantnagar since 1972. Steady decline in rice productivity, after 15 annual rotations, occurred not only with the recommended doses of S-containing mineral NPK fertilizers but also with the integrated use of FYM along with NPKS with average grain yield of rice dropping from 6.2 by 0.123 t/ha/annum during 1972 to 1986 to 4.2 by 0.056 t/ha/annum during 1987 to 1991. However, decling trend in the yield of wheat could be arrested by the application of zinc and sulphur.

Analysis of rice-wheat systems in India reveals that where rice-wheat is intensively farmed (as in Haryana and Punjab), yields of rice have since 1977-78 increased much less rapidly than during 1967-76, a situation somewhat similar to that in China. However, in Haryana and Punjab yields of wheat have risen at roughly constant rates throughout 1975-90. For the less-intensively farmed rice-wheat practising states (such as Bihar, Madhya Pradesh and West Bengal), yields of rice and wheat began to increase in 1980 and have continued to do so thereafter, except for wheat in West Bengal, where yield decline since 1984 is similar to that in neighbouring Bangladesh (Singh and Paroda, 1994).

The IRRI-CIMMYT-NARS diagnostic surveys on rice-wheat systems have revealed that the use of inorganic fertilizers on wheat and rice had increased substantially over the years in order to maintain yields. Experimental data from a 14-year rice-wheat experiment in Nepal showed diminishing rice yields for some treatments, especially those receiving no P. A treatment with FYM (10 t/ha/crop) was as stable as the recommended NPK treatment (100 + 30 + 30 NPK kg/ha for each crop) and resulted in increased total and available P, organic carbon, total nitrogen and available boron in the soil. Long term fertilizer trials at Pantnagar showed gradual decline in rice yield over more than 10 years, ragardless of treatment. Wheat yields, however, did not decline as fast as rice yields and were relatively constant at recommended levels of NPK (Singh and Swarup, 2000).

There are several reports that factor productivity and input-use efficiency are declining under intensive rice-based cropping systems, including rice-wheat systems. To maintain yields, more inputs are needed to counter the declines (Rattan and Singh, 1997). Prasad (1996) mentioned decline in yield and low factor productivity as indicators of sustainability and opined that balanced fertilization, integrated plant nutrient system and *in situ* nutrient cycling are keys which could impart sustainability.

2.5.2 Monitoring Sustainability

Lal (1991) suggested that sustainability can be expressed in terms of output-input as a function of time. It can also be expressed as output per unit consumptive use of the most limiting manageable resources. The following equation has been suggested :

$$S = F\ (P,\ E,\ D,\ C,\ Q)\ T$$

where, S is sustainability index, P is agronomic productivity, E is total energy input, D is a measure of soil degradative process, C is carbon flux from soil and biomass into the atmosphere, Q is a measure of water quality and T is time.

However, sustainable soil productivity is a function of type of soil and environment as soils are easily degraded and it is difficult to sustain productivity over a long period of time. System productivity can also be represented by soil quality. Assessing the quality of soil by way of soil quality parameters that includes soil physical, chemical and biological properties can be used to determine the sustainability of land management (Doran *et al.*, 1994).

Hence, rice-wheat cropping system influence the soil quality which varied from place to place and with different management systems. Combining some of the important key soil quality indicators into a single index, will be more useful in measuring the sustainability of the system.

MATERIALS AND METHODS

The investigation comprised of collection of soil samples, conducting of pot culture studies, analysis of soil samples by recommended standard procedures and subsequent statistical processing of the data. The details are presented below.

3.1 Experiment-1

Soils were collected from rice-wheat fields and the pot culture experiment was carried out.

3.1.1 Collection of soils

For pot culture experiment surface soil (0-20cm) (*Typic Ustochrept)* was collected from Genetics Block of research farm of Indian Agricultural Research Institute, New Delhi. It has previous history of rice culture. The soil samples were air dried and passed through 2 mm sieve and stored until use. The soils were analysed as per the procedures mentioned in this chapter and the results are furnished in Chapter 4, Table 6.

3.1.2 Pot culture experiment

Pot culture experiment was conducted to study the effect of green manure, organic manure, inorganic fertilizers and their combinations on soil characteristics, yield and soil quality.

The soil was mixed with the fertilizers and manures as per the details mentioned in Table 1 and was taken in 10 kg capacity pots with 10 kg soil per pot. Nitrogen, phosphorus, potassium were supplied through urea, single superphosphate and muriate of potash. The amount of farmyard manure

Table 1. Details of fertilizers and manurial doses for pot culture experiment

Treatments		N	P	K	$ZnSO_4$	FYM	Fertilizers	FYM
		---------- (mg/pot) ----------				(g/pot)	(kg/ha)	(t/ha)
O_0	(T_1)	-	-	-	-	0	-	-
O_{120}	(T_2)	-	-	-	-	109	-	24
O_{180}	(T_3)	-	-	-	-	164	-	36
I_0	(T_4)	-	273	273	114	-	0:60:60:25	-
I_{120}	(T_5)	545	273	273	114	-	120:60:60:25	-
I_{180}	(T_6)	818	273	273	114	-	180:60:60:25	-
O_0+I_0	(T_7)	-	273	273	57	-	0:60:60:12.5	-
$O_{60}+I_{60}$	(T_8)	273	273	273	57	54.5	60:60:60:12.5	12
$O_{90}+I_{90}$	(T_9)	409	273	273	57	82	90:60:60:12.5	18

Note: Fertilizers are in N, P_2O_5, K_2O and $ZnSO_4$
The doses were same for both rice and wheat.

was calculated on the basis of N equivalent, so as to supply the same amount of nitrogen as that of inorganic fertilizers. The details of the treatments are given in Table 2. The statistical design followed was two factor completely randomized blocks design with three replications.

The pot culture experiment was carried out using the soil collected from IARI, New Delhi with Green manure-rice-wheat rotation in three growing periods as given in Table 3.

The green manure (*Sesbania spp.)* was harvested and incorporated into the soil and allowed to decompose. There after rice followed by wheat were grown. The fertilizers and manures given were same for both rice and wheat.

3.1.3 Sampling

Soil samples were collected from each pot and used for further analysis. The details of time of sampling is given in Table 4.

3.1.4 Analysis

The soil samples were analysed for pH, EC, bulk density, OC, Available N, P and K, total N, dehydrogenase activity, biomass carbon content and respiration following the procedure mentioned in this chapter.

3.2 Experiment-2

Soil samples were collected directly from the fields where rice-wheat system is in practice.

3.2.1 Collection of soils

Soil samples were collected from 17 locations in Karnal district of Haryana where rice-wheat cropping system has been in practice. The samples

Table 2. Treatments for pot culture experiment

Treatments	with green manure			without green manure		
Organic* (No P_2O_5, K_2O, $ZnSO_4$)	O_0	O_{120}	O_{180}	O_0	O_{120}	O_{180}
**Inorganic$** ($P_2O_5$, K_2O, $ZnSO_4$ @ 60:60:25 kg/ha to all)	I_0	I_{120}	I_{180}	I_0	I_{120}	I_{180}
Organic+inorganic (P_2O_5, K_2O, $ZnSO_4$ @ 60:60:12.5 kg/ha to all)	$O+I_0$	$O+I_{120}$	$O+I_{180}$	$O+I_0$	$O+I_{120}$	$O+I_{180}$

* FYM on 'N' equivalent basis
$ N, P_2O_5, K_2O and $ZnSO_4$ (kg/ha) are supplied through fertilizers
0, 120, 180 are nitrogen levels (kg/ha)

Treatments	=	18	Replication	=	3
Total	=	54	Design	=	2 factor CRD

Table 3. Details of crops, varieties and growth periods for pot culture experiment

S.No.	Crop	Variety	Growing period
1.	Green manure	*Sesbania* spp.	April-98 to May-98
2.	Rice	Pusa-44	July-98 to October-98
3.	Wheat	HD-2687	December-98 to April-99

Table 4. Details of stages of sampling in the pot culture experiment

S.No.	Crop	Stage-I	Stage-II
1.	Rice	45 DAT	90 DAT
2.	Wheat	60 DAS	125 DAS

DAT = days after transplanting
DAS = days after sowing

were collected five times. i.e., initial samples, during rice, after rice, during wheat, after wheat. The collected soil samples were air dried and passed through 2 mm sieve and stored for further analysis.

3.2.2. Analysis

The soil samples were analysed for pH, EC, bulk density, OC, Available N, P and K, total N, dehydrogenase activity, biomass carbon content and respiration following the procedure mentioned in this chapter.

3.3 Methods for Laboratory Analysis

3.3.1 Soil reaction (pH) and EC

Soil pH and EC were determined in 1:2.5 soil-water suspension using combined glass electrode for pH and conductivity bridge for EC as per the procedure described by Jackson (1973).

3.3.2 Bulk density

The core sampler was pushed or driven into the soil to the desired depth (0-15cm) and then removed. Soil samples were dried at 105°C for 48 h in oven. Soil samples were weighed after drying and soil volume computed. Bulk density was calculated by dividing weight of dried soil by its volume (Veihmeyer and Hendrickson, 1948).

3.3.3 Organic carbon

Soil organic carbon was analysed following the procedure given by Walkley and Black (1934).

3.3.4 Total nitrogen

Total nitrogen was estimated by Kjeldahl method i.e., digestion of the soil sample, distillation, collection of the evolved N in boric acid and titration against sulphuric acid (Bremner, 1965).

3.3.5 Available Nitrogen

Available nitrogen was estimated by following the procedure given by Subbiah and Asija (1956). Nitrogen evolved in a alkaline medium was collected in acid and back titrated against alkali.

3.3.6 Available Phosphorus

Olsen's extractant, 0.5M $NaHCO_3$ adjusted to pH 8.5 (Olsen *et al.*, 1954) was used for the extraction of soil available phosphorus. Phosphate in the extract was determined colorimetrically using stannous chloride as the reductant and red filter (660 nm) following the procedure given by Dickman and Bray (1940).

3.3.7 Available potassium

The available potassium was determined in the neutral normal ammonium acetate extract of soil with the help of a flame photometer (Jackson, 1973).

3.3.8 Biomass carbon content

The biomass carbon content in soil was determined by fumigation-extraction method. Moist soil sample was taken in duplicate (to give approximately 20 g of oven dry weight) in 100 ml shaking polypropylene bottles. Another 10 g of the soil was weighed into an aluminium can for the determination of moisture content. One shaking bottle was kept inside a vacuum desiccator and fumigated with fresh ethanol-free chloroform (redistilled twice and washed with concentrated H_2SO_4 followed by two washings with water) for 24 hours and the excess chloroform was removed by repeated evacuation (Jenkinson and Powlson, 1976).

The fumigated sample was extracted with 50 ml of 0.5 M K_2SO_4 (30 minutes shaking) (Brokes *et al.*, 1985) and filtered. Unfumigated sample was extracted with 50 ml of 0.5 M K_2SO_4 immediately after weighing. Carbon content in the extracts of fumigated and unfumigated samples were determined by following the modified procedures of Jenkinson *et al.* (1979) and Tate *et al.* (1988) where 8 ml of the unfumigated extract and 4 ml of fumigated extract (with 4 ml of 0.5 M K_2SO_4) were digested using 2 ml of 0.2 M $K_2Cr_2O_7$ + 10 ml of concentrated H_2SO_4 + 5 ml H_3PO_4 (88%) and the excess potassium dichromate was back titrated with dilute ferrous ammonium sulphate using ferroin as indicator ($\simeq$ 0.015M).

Microbial Biomass Carbon (µg/g soil) = $(OC_F - OC_{UF}) / k_{EC}$

Where :

OC_F = organic carbon extracted from fumigated sample in µg/g soil on oven dry weight basis

OC_{UF} = organic carbon extracted from unfumigated sample in µg/g soil on oven dry weight basis

K_{EC} = efficiency of extraction of microbial biomass carbon ($\simeq$ 0.25 as per Bremner and van Kessel, 1990).

3.3.9 Soil dehydrogenase activity

Dehydrogenase acivity was estimated by monitoring rate of production of triphenyl formazon (TPF) from triphenyl tetrazolium chloride used as an electron acceptor.

The method of Klein *et al.* (1971) was followed for the assay of dehydrogenase activity as outlined below.

One gm of air-dried soil was weighed and placed in 15 ml screw cap ped tube. To this was added 0.2 ml of 3% w/v 2,3,5-triphenyl tetrazolium chloride solution and 0.5 ml of 1% glucose solution ensuring a thin layer of water above the soil. The tubes were incubated at 28 ± 0.5°C for a period of 24 hours. After incubation 10 ml of methanol was added and the tubes were shaken for exactly one minute. These were allowed to stand in dark for six hours. The colour intensity developed was measured colorimetrically at 485 nm (blue filter). From the standard curve, drawn in the range of 0.004 mg TPF to 0.4 mg TPF per 10 ml of methanol, the TPF produced in the incubated samples was computed. Dehydrogenase activity was expressed as TPF formed g^{-1} h^{-1} on oven dry weight basis.

3.3.10 Soil respiration

Soil respiration was measured as the rate of CO_2 evolution from soil (alkali absorption method). The soil was incubated at 25°C and the CO_2 evolved was absorbed in a test tube containing NaOH and this was back titrated against acid (Anderson, 1982).

3.4 Measurement of soil quality

Various methods have been proposed to measure soil quality. In this investigation various soil quality parameters as given in Table 5 was used. Reference values have been established for each of the soil quality indicators used and were given ratings and scores as low (1), medium (2) and high (3). Further to monitor the sustainability of rice-wheat cropping system the following soil quality indices have been used and the results are tabulated in Chapter 4.

METHOD I. **Soil Quality** $= \sum_{i=1}^{13} SQi/13$

Where, **SQi** denotes scores of observed soil quality indicators using Table 5 (The scores are given in Appendix 1, 2 and 3).

METHOD II. **Soil Quality** $= \sum_{i=1}^{13} SQi\ Wi$

Where, **SQi** denotes scores of observed soil quality indicators using Table 5 (The scores are given in Appendix 1, 2 and 3).

Wi denotes the partial R^2 of soil quality parameters obtained in the step wise regression (Appendix 4).

METHOD III. **Soil Quality** $= \sum_{i=1}^{13} SQi\ (BETA)i$

Where, **SQi** denotes scores of observed soil quality indicators using Table 5 (The scores are given in Appendix 1, 2 and 3).

(BETA)i denotes standardised regression coefficient of measured soil quality parameters (Appendix 5).

3.4. Statistical Analysis

All the statistical analysis of the data was carried out in accordance with the procedure suggested by Gomez and Gomez (1984).

Table 5. Ratings for each of the soil quality indicators used in the soil quality index

S.No	Quality Indicators	Low (Score 1)	Moderate (Score 2)	High (Score 3)
1.	pH (1:2.5)	<4.5 >8.5	4.6-6.0 6.1-7.5	7.6-8.4
2.	EC (1:2.5) (dSm^{-1})	>2.0	1-2	<1
3.	Bulk density ($Mg\ m^{-3}$)	>1.7	1.3-1.7	<1.3
4.	Clay (%)	<18, >35	-	18-35
5.	Organic carbon (%)	<0.20	0.20-0.50	>0.50
6.	Total N ($mg\ kg^{-1}$ soil)	<300	300-500	>500
7.	Available N ($mg\ kg^{-1}$ soil)	<115	115-230	>230
8.	Available P ($mg\ kg^{-1}$ soil)	<5.5	5.5-11.0	>11.0
9.	Available K ($mg\ kg^{-1}$ soil)	<50	50-150	>150
10.	Biomass carbon ($mg\ kg^{-1}$ soil)	<75	75-250	>250
11.	Respiration ($mg\ CO_2$-$C\ kg^{-1}\ 24h^{-1}$)	<70	70-140	>140
12.	DHA (μg TPF $g^{-1}\ 24h^{-1}$)	<90	90-180	>180
13.	BC/OC (ratio)	<3.00	-	>3.00
14.	Respiration/BC (ratio)	<0.525	-	>0.525

RESULTS

The results of pot culture experiment with Green manure-Rice-Wheat sequence and the soil samples collected at different locations from Rice-Wheat fields in Karnal district of Haryana are presented in the following headings.

Pot culture experiment

4.1 Characteristics of experimental soil

4.2 Soil quality indicators

Field experiment

4.3 Soil quality indicators

4.4 Soil quality indices

Changes during pot culture experiment

Changes during field experiment

4.5 Sustainability of rice-wheat system

Pot culture experiment

Pot culture experiment was carried out with Green manure-Rice-Wheat using the soil collected from Genetics Block of the farm of IARI, New Delhi. Effect of different fertilizers and manurial treatments (details are given in Table-1 of Chapter 3) on soil quality indicators were studied and the yield was recorded.

4.1 Characteristics of experimental soil

Various soil quality characters of the experimental soils are listed in Table 6. The reaction was slightly alkaline (pH 7.60) and the EC was 0.35 dSm^{-1}. The soil had 26% clay, 0.34% of organic carbon and low in bulk density (1.246 Mgm^{-3}). The available N, P, K and total N was found to be 77,9.0,146 and 604 (mg kg^{-1} soil) respectively.

Some of the important biological indicators like biomass carbon (68 mg kg^{-1} soil), respiration (36 mg CO_2-C kg^{-1} 24 h^{-1}) and the dehydrogenase activity (69 μg TPF g^{-1} soil 24 h^{-1}) were studied. The biomass to organic carbon ratio and the respiration to biomass carbon ratio of experimental soil were found to be 2.00 and 0.529, respectively.

4.2 Soil quality indicators

Effect of green manure and various combinations of organic and inorganic fertilizers (Table 1) on various soil quality indicators in rice-wheat cropping system at various growth stages were studied. The results are presented below.

4.2.1 pH

The pH of soil (Table 7) at 45 days after transplanting of rice (DAT) varied from 7.24 to 7.50. Application of manures and fertilizers and the interaction effects were found to be statistically non-significant. The reaction of soil at harvesting stage of rice ranged from 7.39 to 7.59. Green manuring was non-significant at both the stages of sampling during rice.

The reaction of soil at 60 days after sowing of wheat (DAS) and at harvest stage varied from 7.29 to 7.48 and 7.49 to 7.58, respectively.

Table 6. Initial values of quality indicators of the soil used in pot culture experiment

S. No.	Quality Indicators	Observed value
1.	pH (1 : 2.5)	7.61
2.	EC (1 : 2.5) (dSm^{-1})	0.35
3.	Bulk density (Mgm^{-3})	1.246
4.	Clay (%)	26
5.	Organic carbon (%)	0.34
6.	Total N (mg kg^{-1} soil)	604
7.	Available N (mg kg^{-1} soil)	77
8.	Availabel P (mg kg^{-1} soil)	9.0
9.	Available K (mg kg^{-1} soil)	146
10.	Biomass carbon (mg kg^{-1} soil)	68
11.	Respiration (mg CO_2-C kg^{-1} 24 h^{-1})	36
12.	DHA (µg TPF g^{-1} 24 h^{-1})	69
13.	BC/OC (ratio)	2.000
14.	Respiration/BC (ratio)	0.529

Table 7. pH of soil as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	7.43	7.56	7.50	7.51	7.57	7.54
O_{120}	7.42	7.48	7.45	7.56	7.57	7.57
O_{180}	7.40	7.42	7.41	7.59	7.60	7.59
I_0	7.38	7.40	7.39	7.42	7.42	7.42
I_{120}	7.45	7.47	7.46	7.47	7.47	7.47
I_{180}	7.43	7.43	7.43	7.46	7.45	7.45
O_0+I_0	7.39	7.40	7.40	7.41	7.41	7.41
$O_{60}+I_{60}$	7.41	7.43	7.42	7.45	7.50	7.48
$O_{90}+I_{90}$	7.20	7.28	7.24	7.30	7.49	7.39
Mean	7.39	7.43	7.41	7.46	7.50	7.48

C.D (P=0.05)	Manure = 0.051	C.D (P=0.05)	Manure = 0.053
	Treatments = 0.109		Treatments = 0.111
	M x T = 0.154		M x T = 0.158

	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	7.48	7.48	7.48	7.56	7.58	7.57
O_{120}	7.46	7.48	7.47	7.54	7.56	7.55
O_{180}	7.43	7.43	7.43	7.53	7.52	7.53
I_0	7.41	7.41	7.41	7.57	7.58	7.58
I_{120}	7.47	7.49	7.48	7.55	7.57	7.56
I_{180}	7.42	7.43	7.43	7.52	7.53	7.53
O_0+I_0	7.42	7.45	7.44	7.55	7.56	7.56
$O_{60}+I_{60}$	7.41	7.44	7.43	7.51	7.53	7.52
$O_{90}+I_{90}$	7.28	7.30	7.29	7.48	7.51	7.49
Mean	7.42	7.43	7.43	7.54	7.55	7.54

C.D (P=0.05)	Manure = 0.051	C.D. (P=0.05)	Manure = 0.055
	Treatments = 0.109		Treatments = 0.116
	M x T = 0.154		M x T = 0.164

O - Organic; I - Inorganic; O+I - Organic and Inorganic

0, 120, 180 denotes N equivalent kg/ha.

significant at both the stages of sampling. However, the pH of soil decreased in all the treatments both in rice and wheat when compared to the initial soil pH.

4.2.2 EC

The EC of soil (Table 8) ranged from 0.110 to 0.163 and 0.160 to 0.250 (dSm^{-1}) at 45 DAT and harvest stage of rice, respectively. Green manure application differed significantly with no green manuring to rice. The lowest (0.110 dSm^{-1}) and the highest (0.183 dSm^{-1}) EC values at 45 DAT was observed in the treatment which received inorganic fertilizer nitrogen equivalent to 120 kg ha^{-1} along with green manure and with organic+inorganic control (O_0+I_0), respectively. EC of soil at harvest stage (0.278 dSm^{-1}) was higher than at 45 DAT (0.212 dSm^{-1}).

During growth of wheat, EC varied from 0.195 to 0.241 and 0.250 to 0.312 (dSm^{-1}) at 60 DAS and harvest stage, respectively. The residual effect of green manuring to rice has a significant effect on EC when compared to no green manuring at both the stages of sampling during growth of wheat.

At the end of rice-wheat, EC of soil decreased from the initial value in all the treatments, though it varied in different treatments.

4.2.3 Bulk density

At 45 DAT bulk density ranged from 1.216 to 1.232 Mg m^{-3} (Table 9). Green manuring was found to be non-significant. At harvest stage of rice, BD varied from 1.221 to 1.249 (Mg m^{-3}) and unlike at 45 DAT the green manuring was found to be significant. During rice, lowest BD (1.213 Mgm^{-3}) was observed in the soil which received organic manure @ nitrogen

Table 8. Electrical Conductivity (dSm^{-1}) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	0.160	0.133	0.146	0.160	0.160	0.160
O_{120}	0.140	0.120	0.130	0.173	0.153	0.163
O_{180}	0.160	0.133	0.146	0.240	0.200	0.220
I_0	0.140	0.143	0.142	0.150	0.180	0.165
I_{120}	0.110	0.110	0.110	0.200	0.190	0.195
I_{180}	0.140	0.160	0.150	0.260	0.240	0.250
O_0+I_0	0.183	0.143	0.163	0.200	0.180	0.190
$O_{60}+I_{60}$	0.160	0.120	0.140	0.200	0.180	0.190
$O_{90}+I_{90}$	0.153	0.133	0.143	0.210	0.220	0.215
Mean	0.147	0.133	0.141	0.199	0.189	0.194

C.D (P=0.05)	Manure =	0.0063	C.D (P=0.05)	Manure	=	0.009
	Treatments =	0.013		Treatments	=	0.019
	M x T =	0.018		M x T	=	0.027

	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	0.210	0.230	0.220	0.290	0.300	0.295
O_{120}	0.200	0.210	0.205	0.240	0.260	0.250
O_{180}	0.230	0.253	0.241	0.250	0.280	0.265
I_0	0.200	0.230	0.215	0.303	0.320	0.312
I_{120}	0.190	0.210	0.200	0.250	0.310	0.280
I_{180}	0.200	0.220	0.210	0.260	0.300	0.280
O_0+I_0	0.210	0.210	0.210	0.280	0.300	0.290
$O_{60}+I_{60}$	0.200	0.230	0.215	0.260	0.280	0.270
$O_{90}+I_{90}$	0.190	0.200	0.195	0.250	0.270	0.260
Mean	0.203	0.222	0.212	0.265	0.291	0.278

C.D (P=0.05)	Manure =	0.01	C.D (P=0.05)	Manure	=	0.013
	Treatments =	0.02		Treatments	=	0.027
	M x T =	0.029		M x T	=	0.038

O - Organic; I - Inorganic; O+I - Organic and Inorganic.

Table 9. Bulk Density (Mgm^{-3}) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

Treatments	*RICE*					
	+GM	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
	45 DAT			*90 DAT (HS)*		
O_0	1.222	1.221	1.221	1.233	1.239	1.237
O_{120}	1.223	1.237	1.229	1.237	1.255	1.246
O_{180}	1.213	1.220	1.217	1.219	1.223	1.221
I_0	1.235	1.229	1.232	1.234	1.264	1.249
I_{120}	1.214	1.244	1.229	1.238	1.250	1.244
I_{180}	1.218	1.214	1.216	1.226	1.239	1.233
O_0-I_0	1.234	1.221	1.228	1.252	1.238	1.245
$O_{60}-I_{60}$	1.229	1.219	1.223	1.228	1.223	1.226
$O_{90}+I_{90}$	1.228	1.221	1.225	1.246	1.227	1.237
Mean	1.224	1.225	1.224	1.235	1.240	1.238

C.D (P=0.05)	Manure	= 0.002	C.D (P=0.05)	Manure	= 0.002
	Treatments	= 0.004		Treatments	= 0.004
	M x T	= 0.006		M x T	= 0.006

Treatments	*WHEAT*					
	+GM	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
	60 DAS			*125 DAS (HS)*		
O_0	1.256	1.266	1.271	1.265	1.283	1.274
O_{120}	1.233	1.246	1.239	1.247	1.245	1.246
O_{180}	1.219	1.255	1.237	1.222	1.256	1.239
I_0	1.242	1.272	1.257	1.278	1.270	1.274
I_{120}	1.273	1.267	1.270	1.255	1.266	1.261
I_{180}	1.245	1.256	1.250	1.269	1.264	1.267
O_0-I_0	1.243	1.254	1.248	1.268	1.287	1.278
$O_{60}-I_{60}$	1.239	1.259	1.249	1.240	1.263	1.252
$O_{90}-I_{90}$	1.231	1.239	1.235	1.236	1.252	1.244
Mean	1.245	1.257	1.251	1.253	1.265	1.259

C.D (P=0.05)	Manure	= 0.002	C.D (P=0.05)	Manure	= 0.001
	Treatments	= 0.004		Treatments	= 0.004
	M x T	= 0.006		M x T	= 0.006

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

equivalent to 180 kg ha^{-1} along with green manure ($G.M+O_{180}$) both at 45 DAT and harvest stages, respectively.

At 60 DAS the bulk density of soil varied from 1.235 to 1.271 ($Mg\ m^{-3}$) and at harvest stage ranged from 1.239 to 1.278 ($Mg\ m^{-3}$). The residual effect of green manuring had significant effect in lowering the bulk density at both the stages during wheat. The bulk density of soil during wheat both at 60 DAS (1.252 $Mg\ m^{-3}$) and harvest stage (1.259 $Mg\ m^{-3}$) was higher than the initial value (1.246 $Mg\ m^{-3}$).

During both rice and wheat bulk density increased at harvest stage when compared to bulk density during crop growth (45 DAT in rice and 60 DAS in wheat). In general, the lowest bulk density was observed in green manured soil along with organic manure followed by organic+inorganic and inorganic fertilizers. Bulk density of the soil was negatively correlated ($r = -0.58^{**}$) with organic carbon content in soil.

4.2.4 Organic carbon

The organic carbon content of soil is given in Table 10. During rice, at 45 DAT organic carbon varied from 0.305 to 0.597 (%) and at harvest stage varied from 0.280 to 0.540 (%). Application of green manure had significantly increased the organic carbon content of soil at both the stages. The three treatments which received organic, inorganic, organic+inorganic @ nitrogen equivalent to 180 kg ha^{-1}, respectively, differed significantly at both the stages during rice. However, the trend was observed only at 45 DAT with nitrogen equivalent to 120 kg ha^{-1}.

During wheat, at 60 DAS, the organic carbon content ranged from 0.275 to 0.560 (%) and at harvest stage 0.285 to 0.530 (%). The residual

Table 10. Organic Carbon (%) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		45 DAT			*90 DAT (HS)*	
O_0	0.300	0.310	0.305	0.270	0.290	0.280
O_{120}	0.570	0.420	0.495	0.510	0.400	0.455
O_{180}	0.683	0.510	0.597	0.610	0.470	0.540
I_0	0.337	0.317	0.327	0.350	0.310	0.330
I_{120}	0.390	0.337	0.363	0.400	0.360	0.380
I_{180}	0.437	0.390	0.413	0.437	0.390	0.413
O_0+I_0	0.350	0.310	0.330	0.337	0.310	0.323
$O_{60}+I_{60}$	0.450	0.420	0.435	0.420	0.380	0.400
$O_{90}+I_{90}$	0.510	0.500	0.505	0.500	0.430	0.465
Mean	0.447	0.390	0.419	0.465	0.371	0.399

C.D (P=0.05)	Manure = 0.022	C.D (P=0.05)	Manure = 0.021
	Treatments = 0.046		Treatments = 0.044
	M x T = 0.066		M x T = 0.062

	WHEAT					
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		60 DAS			*125 DAS (HS)*	
O_0	0.270	0.280	0.275	0.290	0.280	0.285
O_{120}	0.553	0.410	0.482	0.490	0.420	0.455
O_{180}	0.620	0.500	0.560	0.580	0.480	0.530
I_0	0.350	0.310	0.330	0.337	0.327	0.332
I_{120}	0.390	0.360	0.375	0.400	0.370	0.385
I_{180}	0.420	0.390	0.405	0.430	0.400	0.415
O_0+I_0	0.350	0.317	0.333	0.350	0.327	0.338
$O_{60}+I_{60}$	0.490	0.450	0.470	0.470	0.410	0.440
$O_{90}+I_{90}$	0.570	0.490	0.530	0.520	0.430	0.475
Mean	0.446	0.389	0.419	0.430	0.383	0.406

C.D (P=0.05)	Manure = 0.022	C.D (P=0.05)	Manure = 0.021
	Treatments = 0.047		Treatments = 0.044
	M x T = 0.066		M x T = 0.063

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

effect of green manure applied to rice, was found to be significant at both the stages during wheat.

Cultivation increased the organic carbon content and it was lower during crop growth stage than at harvest stage both during rice and wheat. During rice and wheat, at all the stages the organic carbon content was found to be lower in all the three control treatments (O_0, I_0 and O_0+I_0) than the initial value.

4.2.5 Total nitrogen

The total nitrogen content of soil (Table 11) during rice varied from 584 to 657 and 567 to 645 (mg kg^{-1} soil) at 45 DAT and harvest stage, respectively. Application of green manure significantly increased the total nitrogen content of soil at both the stages. The three treatments (organic, inorganic, organic + inorganic) which received no nitrogen, was found to contain lower total nitrogen than initial value (604 mg kg^{-1} soil) both at 45 DAT and harvest stage of rice. Increase in the rate of nitrogen application increased the total nitrogen content in all the treatments. Total nitrogen content at maturity was lower than at 45 DAT in all the treatments except the treatment which received nitrogen @ 120 kg ha^{-1} as inorganic fertilizer (I_{120}).

During wheat the total nitrogen content varied from 566 to 648 and 568 to 638 (mg kg^{-1} soil) at 60 DAS and harvest stage, respectively. There was a significant residual effect on total nitrogen content at both the stages during wheat.

In both rice and wheat, total soil nitrogen was more in green manured soils. Further, the results indicated that application of organic manures @

Table 11. Total Nitrogen (mg kg[-1] soil) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	586	583	584	580	554	567
O_{120}	650	619	634	636	620	628
O_{180}	680	634	657	660	631	645
I_0	594	590	592	593	586	589
I_{120}	612	601	606	615	604	609
I_{180}	620	611	615	619	610	614
O_0+I_0	602	586	594	600	585	592
$O_{60}+I_{60}$	619	617	618	618	608	613
$O_{90}+I_{90}$	635	628	632	633	617	625
Mean	622	607	614	617	601	609

C.D (P=0.05)				C.D (P=0.05)			
	Manure	=	4.73		Manure	=	4.63
	Treatments	=	10.03		Treatments	=	9.83
	M x T	=	14.18		M x T	=	13.90

	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	580	552	566	586	551	568
O_{120}	642	630	636	627	622	624
O_{180}	664	632	648	652	624	638
I_0	595	587	591	594	591	592
I_{120}	612	606	609	614	607	610
I_{180}	620	612	616	621	612	616
O_0+I_0	593	587	590	592	588	590
$O_{60}+I_{60}$	620	619	619	619	616	617
$O_{90}+I_{90}$	648	627	638	653	621	637
Mean	619	606	612	617	603	610

C.D (P=0.05)				C.D (P=0.05)			
	Manure	=	4.67		Manure	=	4.6
	Treatments	=	9.92		Treatments	=	9.77
	M x T	=	14.03		M x T	=	13.81

nitrogen equivalent to 180 kg ha^{-1} had a higher total nitrogen in all the stages during rice and wheat. Except three control treatments (O_0, I_0 and O_0+I_0) during rice and wheat. total nitrogen increased with the increase in application of nitrogen and it followed in the order of organic followed by organic + inorganic and inorganic.

4.2.6 Available nitrogen

The available nitrogen during rice varied from 68.8 to 132.5 and 69.7 to 125.0 mg kg^{-1} soil at 45 DAT and harvest stage, respectively (Table 12). Green manuring had a significant effect on the available nitrogen content at both the stages. Increased level of application of fertilizers was found to have positive effect on the available nitrogen content. In general, at harvest stage available nitrogen was lower than at 45 DAT.

During wheat available nitrogen ranged from 71.3 to 131.0 and 71.0 to 122.5 mg kg^{-1} soil at 60 DAS and harvest stage, respectively. The residual effect of application of green manure to rice was found to be significant at both the stages during wheat. Available nitrogen content was lower at harvest stage than at 60 DAS. Otherwise, the available nitrogen followed the same trend as in the case of rice.

The changes in available nitrogen level (initial available nitrogen was substracted from the values of different treatments) shows that both during rice and wheat there was a negative balance for all the three control treatments (Fig. 1). The higher negative balance was observed in inorganic control (I_0) during rice and in organic control (O_0) during wheat. In general, the balance was lower in the treatments which received no green manure. The residual effect of green manuring on available nitrogen was more pronounced in organic followed by organic + inorganic and inorganic.

Table 12. Available nitrogen (mg kg^{-1} soil) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		45 DAT			*90 DAT (HS)*	
O_0	78.0	75.0	76.5	74.0	68.0	71.0
O_{120}	120.0	111.3	115.7	112.3	109.3	110.8
O_{180}	136.0	124.0	130.0	130.0	120.0	125.0
I_0	70.7	67.0	68.8	72.0	69.7	70.8
I_{120}	118.0	115.0	116.5	110.3	108.3	109.3
I_{180}	132.0	120.0	126.0	121.0	116.0	118.5
O_0+I_0	72.0	68.0	70.0	70.7	68.7	69.7
$O_{60}+I_{60}$	119.0	118.0	118.5	11.3	106.3	108.8
$O_{90}+I_{90}$	134.0	131.0	132.5	126.0	124.0	125.0
Mean	108.9	103.3	106.1	103.1	99.0	109.0

C.D (P=0.05)	Manure = 1.266	C.D (P=0.05)	Manure = 1.178
	Treatments = 2.685		Treatments = 2.499
	M x T = 3.798		M x T = 3.534

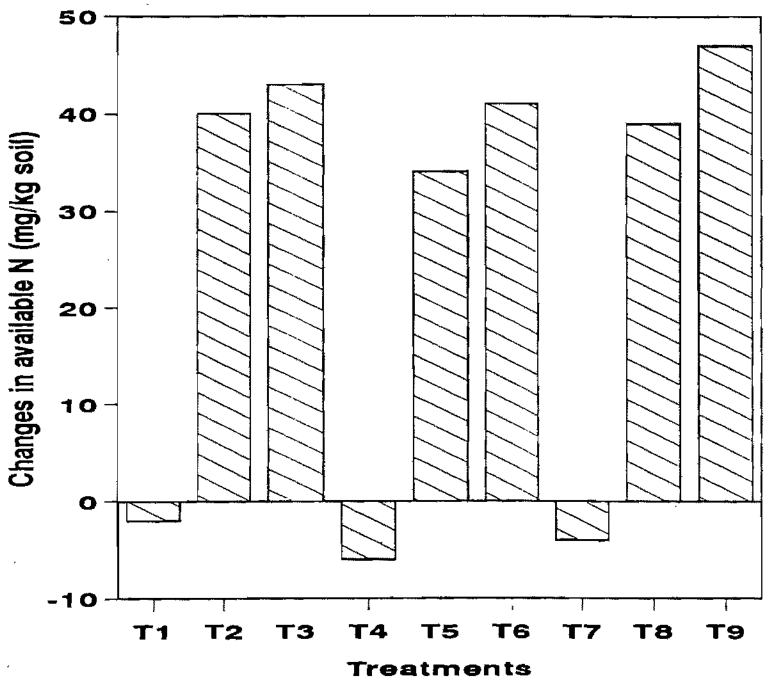
	WHEAT					
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		60 DAS			*125 DAS (HS)*	
O_0	74.0	69.7	71.8	75.0	67.0	71.0
O_{120}	118.0	113.3	115.7	117.0	110.3	113.7
O_{180}	133.0	129.0	131.0	120.0	122.0	121.0
I_0	72.0	74.0	73.0	70.7	72.0	71.3
I_{120}	116.0	114.0	115.0	111.3	110.3	110.8
I_{180}	127.0	119.0	123.0	118.0	115.0	116.5
O_0+I_0	70.7	72.0	71.3	73.0	70.7	71.8
$O_{60}+I_{60}$	122.0	116.0	119.0	116.0	114.0	115.0
$O_{90}+I_{90}$	130.0	128.0	129.0	124.0	121.0	122.5
Mean	106.9	103.9	105.4	102.8	100.3	101.5

C.D (P=0.05)	Manure = 1.288	C.D (P=0.05)	Manure = 1.239
	Treatments = 2.732		Treatments = 2.628
	M x T = 3.864		M x T = 3.716

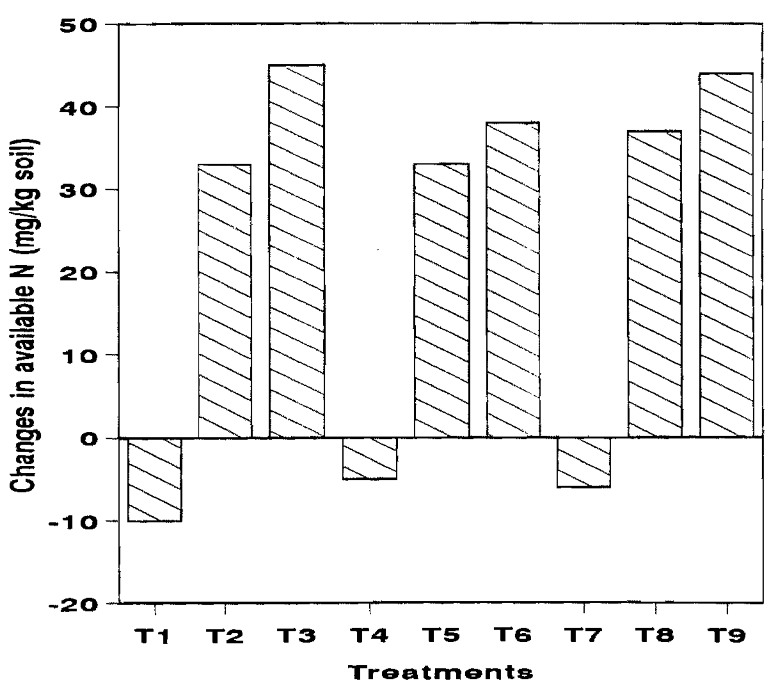
O - Organic; I - Inorganic; O + I - Organic and Inorganic.

Fig.1 Changes in available N level in rice-wheat system

a. With green manure



b. Without green manure



4.2.7 Available phosphorus

During rice (Table 13) at 45 DAT and harvest stage the available phosphorus varied from 6.90 to 14.25 and 5.90 to 13.90 mg kg^{-1} soil, respectively. Green manuring increased the available phosphorus content and it was found to be statistically significant at both the stages.

During wheat, the available phosphorus content varied from 5.80 to 14.19 and 5.58 to 13.90 mg kg^{-1} soil at 60 DAS and harvest stage, respectively. The residual effect of application of green manure was found to be significant at both the stages.

The available phosphorus increased with the increase in the application rate of fertilizers both during rice and wheat and in all the stages. Further, it was observed that the highest available phosphorus was in the treatment which received organic+inorganic @ nitrogen equivalent to 180 kg ha^{-1} ($O_{90}+I_{90}$) and lowest at organic control (O_0) which received no fertilizer.

In general, available phosphorus content was more in the treatments which received organic+inorganic fertilizers followed by inorganic and organic. The changes in available phosphorus level (Fig. 2) shows that both during rice and wheat there was a negative balance in all the three control treatments. However, higher negative balance was found in organic control treatment (O_0) both during rice and wheat. But green manuring reduced the negative balance in available phosphorus.

4.2.8 Available potassium

The available potassium content during rice (Table 14) ranged from 139.5 to 173.5 and 131.5 to 162.7 mg kg^{-1} soil at 45 DAT and harvest stage, respectively. Green manuring significantly increased the available

Table 13. Available phosphorus (mg kg^{-1} soil) as affected by fertilizer and manurial treatments at different growth stages under rice-wheat system

			RICE			
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		45 DAT			*90 DAT (HS)*	
O_0	7.60	6.20	6.90	7.30	4.50	5.90
O_{120}	9.40	8.90	9.15	9.30	8.50	8.90
O_{180}	11.90	11.03	11.47	11.70	10.73	11.22
I_0	8.90	8.50	8.70	8.70	8.20	8.45
I_{120}	13.70	13.40	13.55	13.70	13.30	13.50
I_{180}	14.10	13.80	13.95	13.80	13.30	13.55
O_0+I_0	8.80	8.70	8.75	8.60	8.10	8.35
$O_{60}+I_{60}$	13.90	13.80	13.85	13.80	13.70	13.75
$O_{90}+I_{90}$	14.40	14.10	14.25	14.00	13.80	13.90
Mean	11.41	10.94	11.17	11.21	10.46	10.84

C.D (P=0.05) Manure = 0.123; Treatments = 0.261; M x T = 0.369 — C.D (P=0.05) Manure = 0.123; Treatments = 0.261; M x T = 0.369

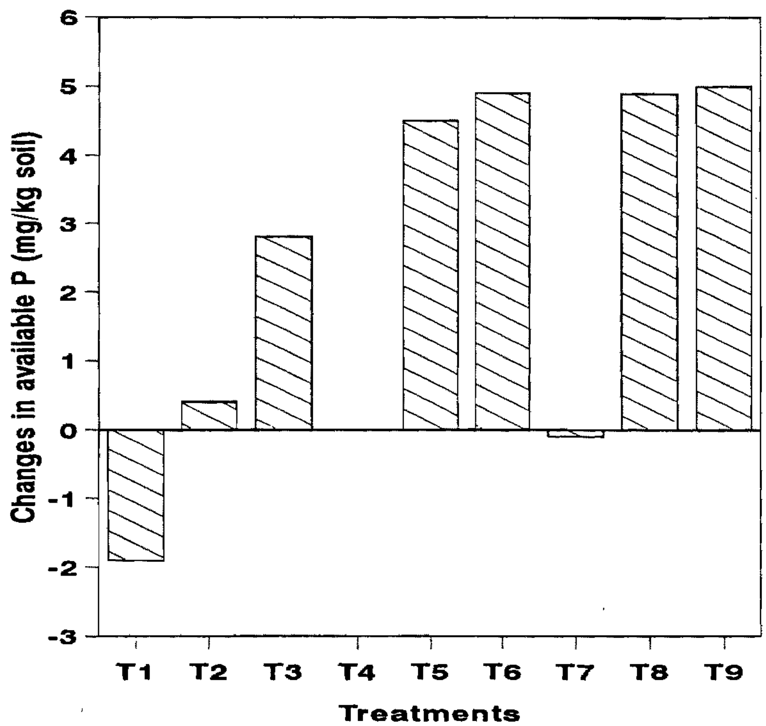
			WHEAT			
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		60 DAS			*125 DAS (HS)*	
O_0	7.40	4.20	5.80	7.07	4.10	5.58
O_{120}	9.50	9.00	9.25	9.40	9.20	9.30
O_{180}	12.00	11.13	11.57	11.80	10.93	11.37
I_0	9.20	8.60	8.90	9.00	8.50	8.75
I_{120}	13.90	13.60	13.75	13.50	13.20	13.35
I_{180}	14.20	13.80	14.00	13.90	13.60	13.75
O_0+I_0	9.00	8.60	8.80	8.90	8.40	8.65
$O_{60}+I_{60}$	14.10	13.70	13.90	13.90	13.50	13.70
$O_{90}+I_{90}$	14.20	14.00	14.19	14.00	13.80	13.90
Mean	11.50	10.74	11.12	11.27	10.58	10.93

C.D (P=0.05) Manure = 0.123; Treatments = 0.261; M x T = 0.369 — C.D (P=0.05) Manure = 0.123; Treatments = 0.260; M x T = 0.368

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

Fig.2 Changes in available P level in rice-wheat system

a. With green manure



b. Without green manure

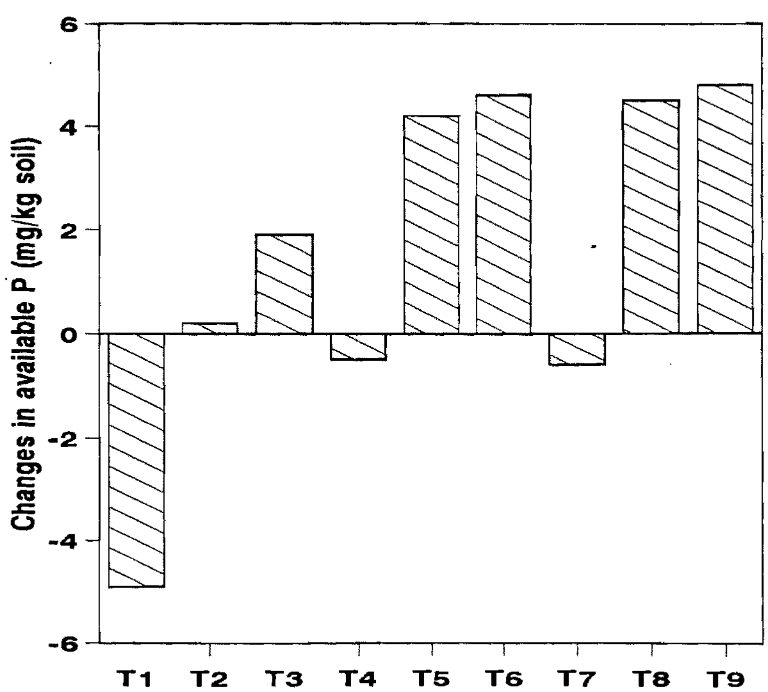


Table 14. Available K (mg kg^{-1} soil) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	142.0	137.0	139.5	134.0	129.0	131.5
O_{120}	164.7	160.7	162.7	151.0	148.0	149.5
O_{180}	170.0	169.0	169.5	163.7	161.7	162.7
I_0	167.0	157.0	162.0	130.0	155.0	142.5
I_{120}	158.0	149.0	153.5	150.0	143.0	146.5
I_{180}	159.0	145.0	152.0	148.0	142.0	145.0
O_0+I_0	169.0	161.7	165.3	144.0	151.0	147.5
$O_{60}+I_{60}$	171.0	164.7	167.8	162.7	150.0	156.3
$O_{90}+I_{90}$	178.0	169.0	173.5	164.7	151.0	157.8
Mean	164.3	157.0	160.6	149.8	147.9	148.8

C.D (P=0.05) Manure = 1.752; Treatments = 3.716; M x T = 5.256

C.D (P=0.05) Manure = 1.536; Treatments = 3.258; M x T = 4.607

	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	130.0	130.0	130.0	133.0	129.0	131.0
O_{120}	158.0	156.0	157.0	153.0	147.0	150.0
O_{180}	169.0	167.0	168.0	159.0	156.0	157.5
I_0	160.7	159.7	160.2	157.0	155.0	156.0
I_{120}	159.7	156.0	157.8	149.0	150.0	149.5
I_{180}	158.0	154.0	156.0	143.0	148.0	145.5
O_0+I_0	161.7	159.0	160.3	158.0	153.0	155.5
$O_{60}+I_{60}$	178.0	157.0	167.5	154.0	145.0	149.5
$O_{90}+I_{90}$	181.0	156.0	168.5	154.0	143.0	148.5
Mean	161.8	155.0	158.4	151.1	147.3	149.2

C.D (P=0.05) Manure = 1.663; Treatments = 3.527; M x T = 4.988

C.D (P=0.05) Manure = 1.460; Treatments = 3.098; M x T = 4.381

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

potassium at both the stages. At 45 DAT the treatments and their interactions both at nitrogen equivalent to 120 and 180 kg ha^{-1} level varied significantly. The same trend was observed at harvest stage with nitrogen equivalent to 180 kg ha^{-1}. During rice, the highest (178.0 mg kg^{-1} soil) and lowest (129.0 mg kg^{-1} soil) available potassium was observed in the treatment which received organic + inorganic @ nitrogen equivalent to 180 kg ha^{-1} ($O_{90}+I_{90}$) along with green manure at 45 DAT and the organic control treatment (O_0) at harvest stage.

The available potassium content during wheat varied from 130.0 to 168.5 and 131.0 to 157.5 mg kg^{-1} soil at 60 DAS and harvest stage, respectively. There was a significant difference due to residual effect of green manuring at both the stages. The highest and lowest available potassium content followed the same trend as that of rice. In general, available potassium was lower at harvest stage than at crop growth stage (45 DAT in rice and 60 DAS in wheat) during rice and wheat.

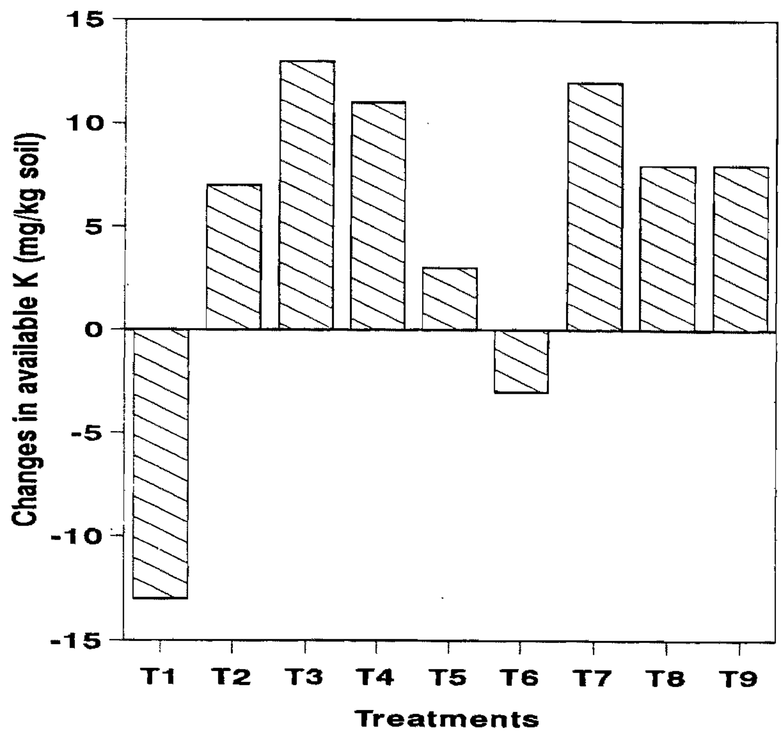
Fig. 3 shows that there was a greater net negative balance of available potassium in the treatments which received no K fertilizer (G.M+O_0 and O_0). However, the magnitude of imbalance was more in no green manurial treatment (O_0). Greater positive balance was observed in the treatment which received organic manure @ nitrogen equivalent to 180 kg ha^{-1} either with or without green manure.

4.2.9 Biomass carbon

The biomass carbon content of soil during rice-wheat is given in Table 15. The results showed that the biomass carbon content of soil during rice varied from 71.8 to 175.5 mg kg^{-1} soil at 45 DAT and 69.3 to 168.8 mg

Fig.3 Changes in available K level in rice-wheat system

a. With green manure



b. Without green manure

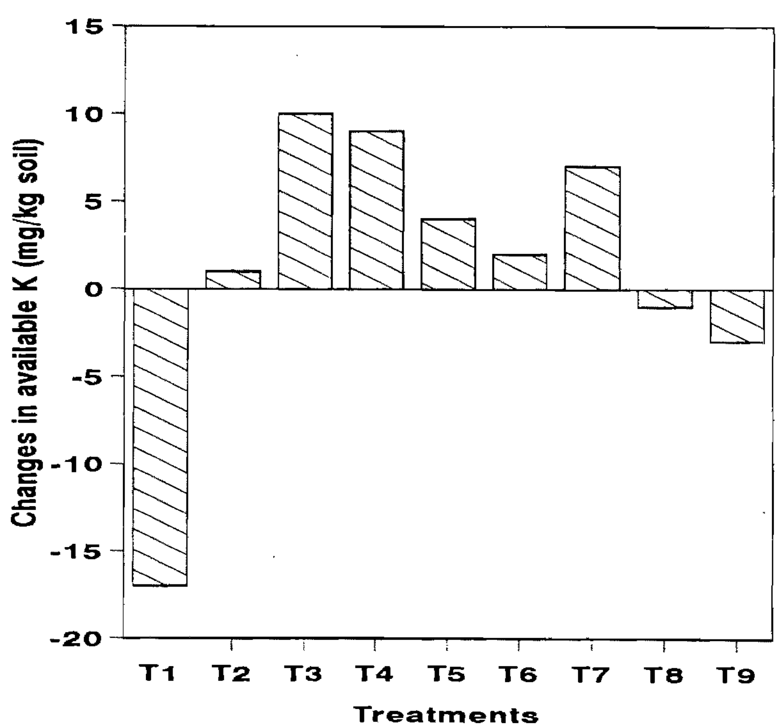


Table 15. Biomass carbon (mg kg^{-1} soil) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

Treatments	*WHEAT* 60 DAS *+GM*	*-GM*	*Mean*	125 DAS (HS) *+GM*	*-GM*	*Mean*
O_0	75.0	73.0	74.0	73.0	72.0	72.5
O_{120}	160.7	117.0	138.8	143.0	106.3	124.7
O_{180}	178.0	132.0	155.0	171.0	127.0	149.0
I_0	73.0	70.7	71.8	70.7	68.7	69.7
I_{120}	119.0	102.3	110.7	109.3	100.0	104.7
I_{180}	124.0	108.3	116.2	115.0	101.3	108.2
O_0+I_0	74.0	70.7	72.3	70.7	68.0	69.3
$O_{60}+I_{60}$	164.7	140.0	152.3	147.0	125.0	136.0
$O_{90}+I_{90}$	180.0	171.0	175.5	178.0	159.7	168.8
Mean	127.6	109.4	118.5	119.7	103.1	111.4

C.D (P=0.05)				C.D (P=0.05)			
	Manure	=	1.425		Manure	=	1.309
	Treatments	=	3.023		Treatments	=	2.778
	M x T	=	4.276		M x T	=	3.929

Treatments	*RICE* 60 DAT *+GM*	*-GM*	*Mean*	125 DAT (HS) *+GM*	*-GM*	*Mean*
O_0	78.0	75.0	76.5	77.0	73.0	75.0
O_{120}	167.0	119.0	143.0	162.7	114.0	138.3
O_{180}	179.0	129.0	154.0	175.0	127.0	151.0
I_0	74.0	72.0	73.0	72.0	70.7	71.3
I_{120}	120.0	107.3	113.7	115.0	105.3	110.2
I_{180}	131.0	119.0	125.0	122.0	117.0	119.5
O_0+I_0	76.0	70.7	73.3	73.0	69.7	71.3
$O_{60}+I_{60}$	180.0	156.0	168.0	172.0	138.0	155.0
$O_{90}+I_{90}$	212.7	172.0	192.3	193.0	149.0	171.0
Mean	135.3	113.3	124.3	129.1	107.1	118.1

C.D (P=0.05)				C.D (P=0.05)			
	Manure	=	1.500		Manure	=	1.421
	Treatments	=	3.183		Treatments	=	3.015
	M x T	=	4.501		M x T	=	4.264

kg^{-1} soil at harvest stage. Except control there was a significant difference among all other treatments at the same nitrogen equivalent level both at 45 DAT and harvest stage. The highest biomass carbon content 180.0 mg kg^{-1} soil was observed in the treatment which received organic+inorganic (O_{90}+I_{90}) @ nitrogen equivalent to 180 kg ha^{-1} along with green manure at 45 DAT. The lowest 68.0 mg kg^{-1} soil was observed in the organic + inorganic control (O_0+I_0) with no green manure at harvest stage.

During wheat biomass content varied from 73.0 to 192.3 and 71.3 to 171.0 mg kg^{-1} soil at 60 DAS and harvest stage, respectively. The highest (212.7 mg kg^{-1} soil) and lowest (69.7 mg kg^{-1} soil) biomass carbon content was observed in the treatments as in the case of rice.

Application of green manure to rice had significant influence in the biomass carbon content at all the stages during rice and wheat (Fig. 4). Further, cultivation increased biomass carbon content in all the treatments than the initial value (68 mg kg^{-1} soil). Biomass carbon content was lower at harvest stage than at 45 DAT during rice and the same trend was observed during wheat also.

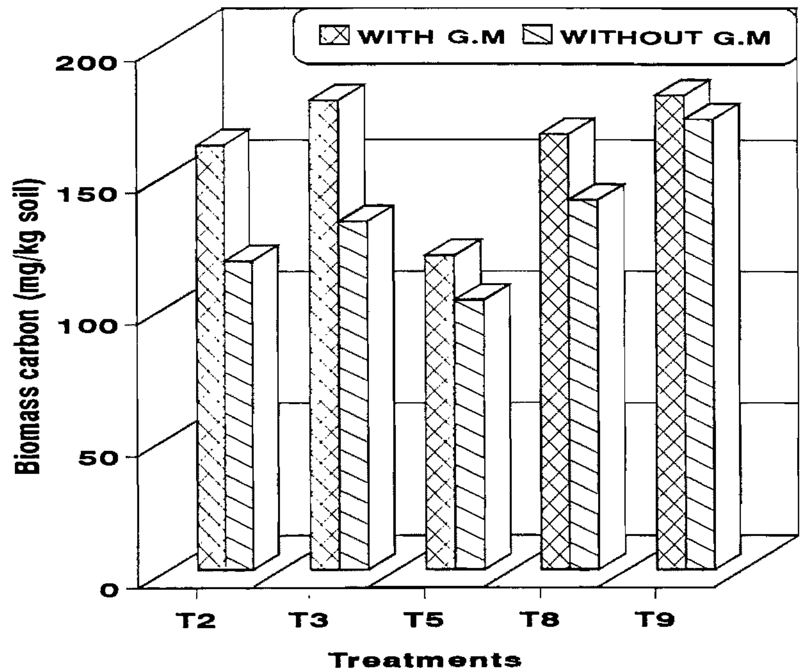
4.2.10 Respiration

During rice, the respiration (Table 16) ranged from 35.0 to 82.5 mg CO_2-C kg^{-1} 24 h^{-1} at 45 DAT and from 32.8 to 76.5 mg CO_2-C kg^{-1} 24 h^{-1} at harvest stage. Green manuring increased respiration and differed significantly with no green manuring at both the stages during rice.

The respiration during wheat, varied from 36.5 to 82.5 mg CO_2-C kg^{-1} 24 h^{-1} at 60 DAS and from 33.8 to 80.5 mg CO_2-C kg^{-1} 24 h^{-1} at harvest stage. There was significant residual effect in respiration during wheat due

Fig.4 Effect of different fertilizers and manurial treatments on the biomass carbon

a. At 45 DAT in rice



b. At 60 DAS in wheat

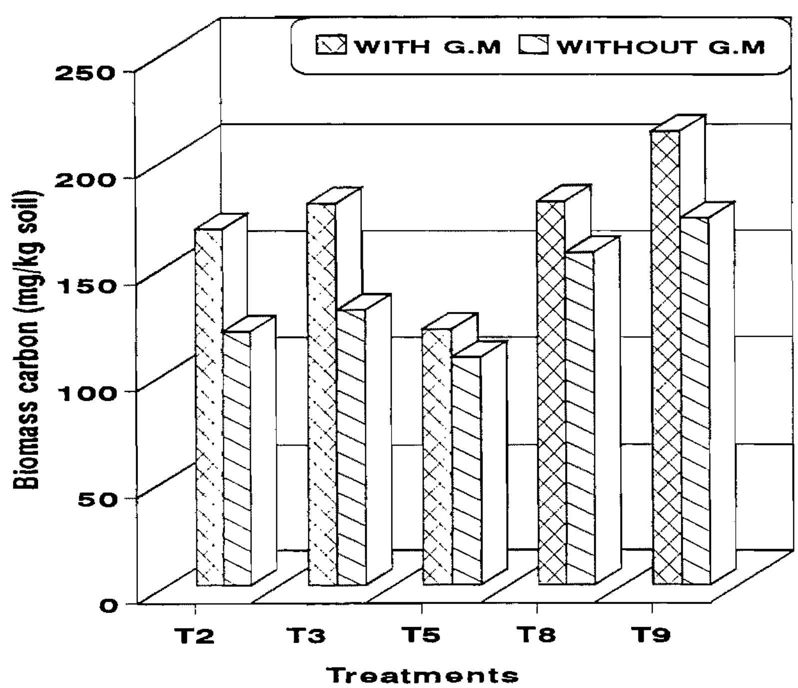


Table 16. Respiration (mg CO_2-C kg^{-1} soil 24 h^{-1}) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

RICE						
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		45 DAT			*90 DAT (HS)*	
O_0	38.0	34.0	36.0	36.0	31.7	33.8
O_{120}	83.0	79.0	81.0	73.0	72.0	72.5
O_{180}	79.0	73.0	76.0	70.7	70.7	70.7
I_0	37.0	35.0	36.0	36.0	32.7	34.3
I_{120}	79.0	65.0	72.0	72.0	64.0	68.0
I_{180}	70.7	64.0	67.3	63.0	64.0	63.5
O_0+I_0	35.0	35.0	35.0	34.0	31.7	32.8
$O_{60}+I_{60}$	80.0	72.0	76.0	75.0	68.7	71.8
$O_{90}+I_{90}$	87.0	78.0	82.5	78.0	75.0	76.5
Mean	65.4	59.4	62.4	59.7	56.7	58.2

C.D (P=0.05)	Manure	= 0.795	C.D (P=0.05)	Manure	= 0.736
	Treatments	= 1.686		Treatments	= 1.561
	M x T	= 2.385		M x T	= 2.208

WHEAT						
Treatments	*+GM*	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
		60 DAS			*125 DAS (HS)*	
O_0	40.0	39.0	39.5	38.0	32.7	35.3
O_{120}	85.0	80.0	82.5	83.0	78.0	80.5
O_{180}	80.0	70.7	75.3	81.0	69.7	75.3
I_0	37.0	36.0	36.5	36.0	31.7	33.8
I_{120}	79.0	66.0	72.5	75.0	64.0	69.5
I_{180}	72.0	68.0	70.0	69.7	65.0	67.3
O_0+I_0	39.0	35.0	37.0	38.0	34.0	36.0
$O_{60}+I_{60}$	82.0	75.0	78.5	81.0	70.7	75.8
$O_{90}+I_{90}$	81.0	79.0	80.0	77.0	74.0	75.5
Mean	66.1	60.9	63.5	64.3	57.7	61.0

C.D (P=0.05)	Manure	= 0.795	C.D (P=0.05)	Manure	= 0.766
	Treatments	= 1.686		Treatments	= 1.625
	M x T	= 2.385		M x T	= 2.298

to green manuring to rice. High doses of fertilizers reduced the respiration especially inorganic nitrogen fertilizer. The respiration was more during crop growth stage (45 DAT in rice and 60 DAS in wheat) than at maturity (t1>t2 and t3>t4) in rice-wheat (Fig. 5).

4.2.11 Dehydrogenase activity

The dehydrogenase activity (DHA) during rice (Table 17) ranged from 71.8 to 111.5 and 66.0 to 101.7 μg TPF g^{-1} soil 24 h^{-1} at 45 DAT and harvest stage, respectively. Application of green manure significantly increased DHA at both the stages during rice.

The same trend was observed during wheat where it ranged from 56.5 to 106.5 and 62.0 to 103.2 μg TPF g^{-1} soil 24 h^{-1} at 60 DAS and harvest stage, respectively. The residual effect of green manuring to rice was found to be statistically significant. Throughout the rice-wheat the lowest value was observed in control (O_0) and highest value in the treatment which received organic manure @ nitrogen equivalent to 180 kg ha^{-1} (O_{180}).

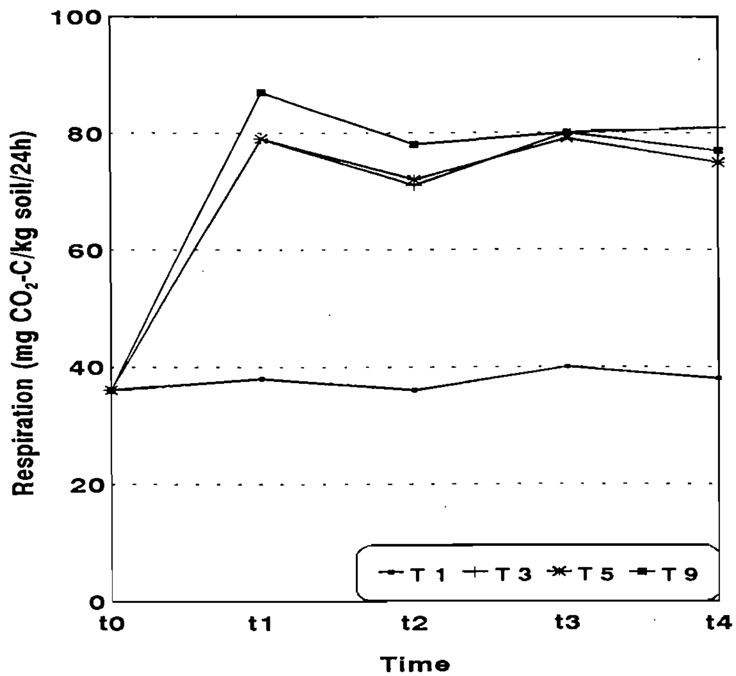
DHA increased with increase in the rate of manures and fertilizers (Fig. 6). In general DHA was more in organic followed by organic+inorganic and inorganic fertilization except in control. DHA was more during crop growth than at harvest stage. Further, it was observed that except in organic control treatment (O_0) all other treatments have higher DHA than the initial stage (69 μg TPF g^{-1} soil 24 h^{-1}).

4.2.12 Biomass to organic carbon ratio

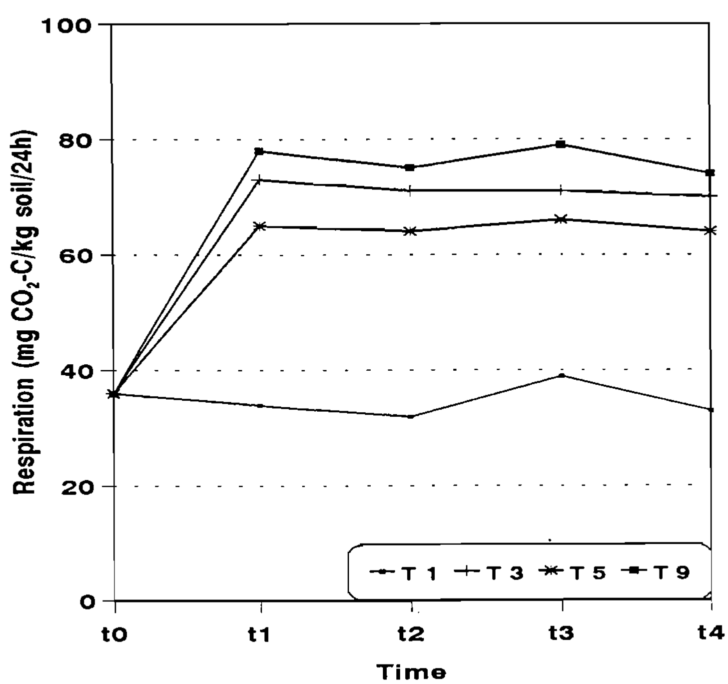
The biomass to organic carbon ratio (BMOC) varied from 2.193 to 3.517 at 45 DAT and 2.137 to 3.656 at harvest stage (Table 18). Green manuring was found to be non-significant. During wheat, at 60 DAS and

Fig. 5 Effect of different fertilizers and manurial treatments on respiration

a. With green manure



b. Without green manure



*stages of sampling (t) are given in Table-4

Table 17. Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1}) as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

RICE						
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	70.7	73.0	71.8	60.0	72.0	66.0
O_{120}	109.3	81.0	95.2	103.3	79.0	91.2
O_{180}	125.0	98.0	111.5	112.3	91.0	101.7
I_0	76.0	70.7	73.3	84.0	69.7	76.8
I_{120}	86.0	82.0	84.0	79.0	81.0	80.0
I_{180}	91.0	85.0	88.0	93.0	86.0	89.5
O_0+I_0	75.0	74.0	74.5	75.0	73.0	74.0
$O_{60}+I_{60}$	96.0	80.0	88.0	89.0	84.0	86.5
$O_{60}+I_{90}$	103.3	96.0	99.7	102.3	79.0	90.7
Mean	92.5	82.2	87.3	88.7	79.4	84.0

C.D (P=0.05) Manure = 1.002; Treatments = 2.126; M x T = 3.006 — C.D (P=0.05) Manure = 0.968; Treatments = 2.053; M x T = 2.903

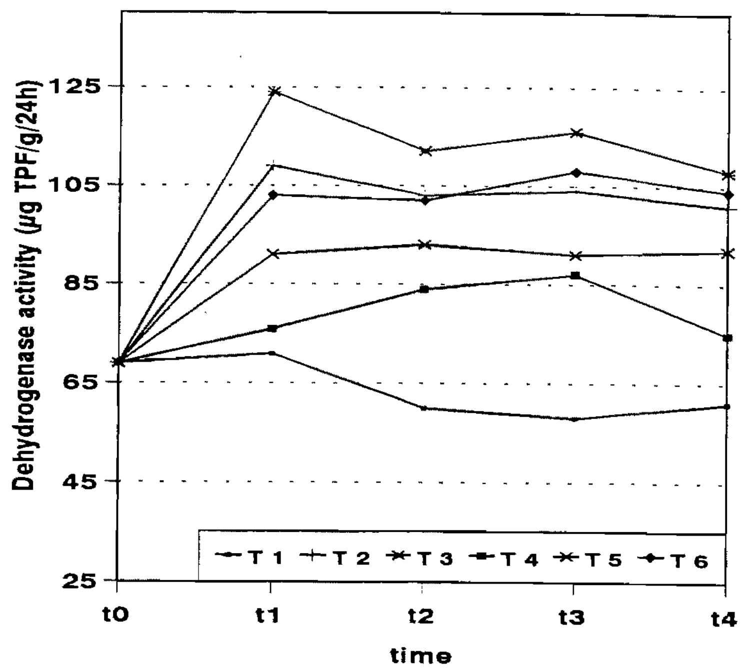
WHEAT						
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	58.0	55.0	56.5	61.0	63.0	62.0
O_{120}	104.3	83.0	93.7	101.3	80.0	90.7
O_{180}	116.0	97.0	106.5	108.3	98.0	103.2
I_0	87.0	69.7	78.3	75.0	73.0	74.0
I_{120}	88.0	80.0	84.0	79.0	81.0	80.0
I_{180}	91.0	87.0	89.0	92.0	79.0	85.5
O_0+I_0	75.0	74.0	74.5	74.0	72.0	73.0
$O_{60}+I_{60}$	100.0	97.0	98.5	94.0	79.0	86.5
$O_{60}+I_{90}$	108.3	102.3	105.3	104.3	80.0	92.2
Mean	92.0	82.8	87.4	87.7	78.3	83.0

C.D (P=0.05) Manure = 0.985; Treatments = 2.090; M x T = 2.955 — C.D (P=0.05) Manure = 0.956; Treatments = 2.028; M x T = 2.868

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

Fig. 6. Effect of different fertilizers and manurial treatments on dehydrogenase activity

a. With green manure



b. Without green manure

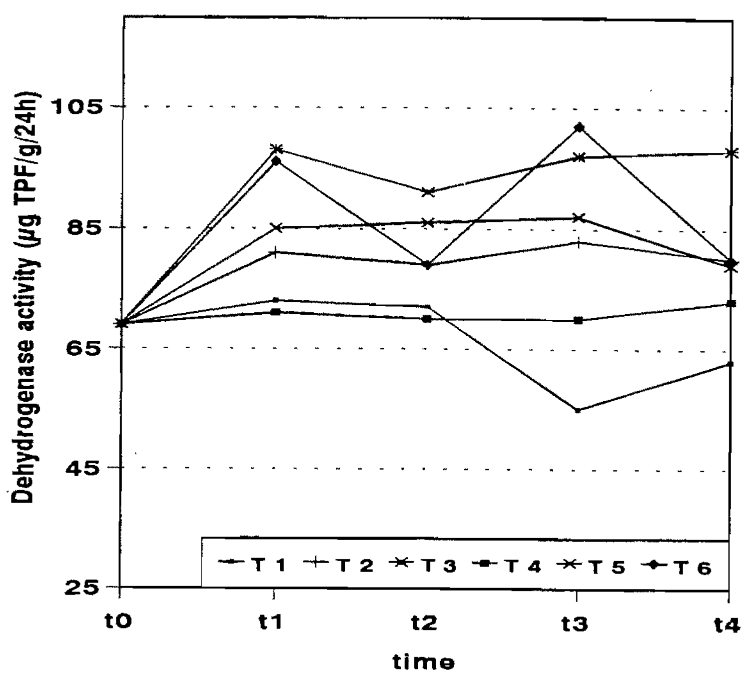


Table 18. Biomass carbon to organic carbon as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	2.513	2.363	2.438	2.713	2.493	2.603
O_{120}	2.837	2.797	2.817	2.817	2.663	2.740
O_{180}	2.630	2.600	2.615	2.817	2.713	2.765
I_0	2.157	2.230	2.193	2.037	2.237	2.137
I_{120}	3.067	3.013	3.040	2.737	2.787	2.762
I_{180}	2.833	2.783	2.808	2.627	2.600	2.613
O_0+I_0	2.123	2.297	2.210	2.100	2.200	2.150
$O_{60}+I_{60}$	3.683	3.350	3.517	3.517	3.307	3.412
$O_{90}+I_{90}$	3.547	3.437	3.492	3.573	3.737	3.656
Mean	2.821	2.763	2.792	2.771	2.749	2.759

C.D (P=0.05)	Manure = 0.113		C.D (P=0.05)	Manure = 0.113	
	Treatments = 0.24			Treatments = 0.24	
	M x T = 0.339			M x T = 0.338	

	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	2.903	2.690	2.797	2.667	2.620	2.643
O_{120}	3.050	2.917	2.983	3.343	2.727	3.035
O_{180}	2.900	2.590	2.745	3.030	2.657	2.843
I_0	2.123	2.333	2.228	2.127	2.163	2.145
I_{120}	3.090	2.983	3.037	2.887	2.853	2.870
I_{180}	3.133	3.067	3.100	2.853	2.940	2.897
O_0+I_0	2.180	2.230	2.205	2.093	2.130	2.111
$O_{60}+I_{60}$	3.690	3.483	3.587	3.677	3.383	3.530
$O_{90}+I_{90}$	3.753	3.527	3.640	3.727	3.480	3.603
Mean	2.980	2.869	2.925	2.934	2.773	2.853

C.D (P=0.05)	Manure = 0.119		C.D (P=0.05)	Manure = 0.116	
	Treatments = 0.252			Treatments = 0.247	
	M x T = 0.357			M x T = 0.349	

O - Organic; I - Inorganic; O + I - Organic and Inorganic harvest stage it ranged from 2.205 to 3.640 and 2.111 to 3.603, respectively. Residual effect of green manuring was found to be significant at harvest stage.

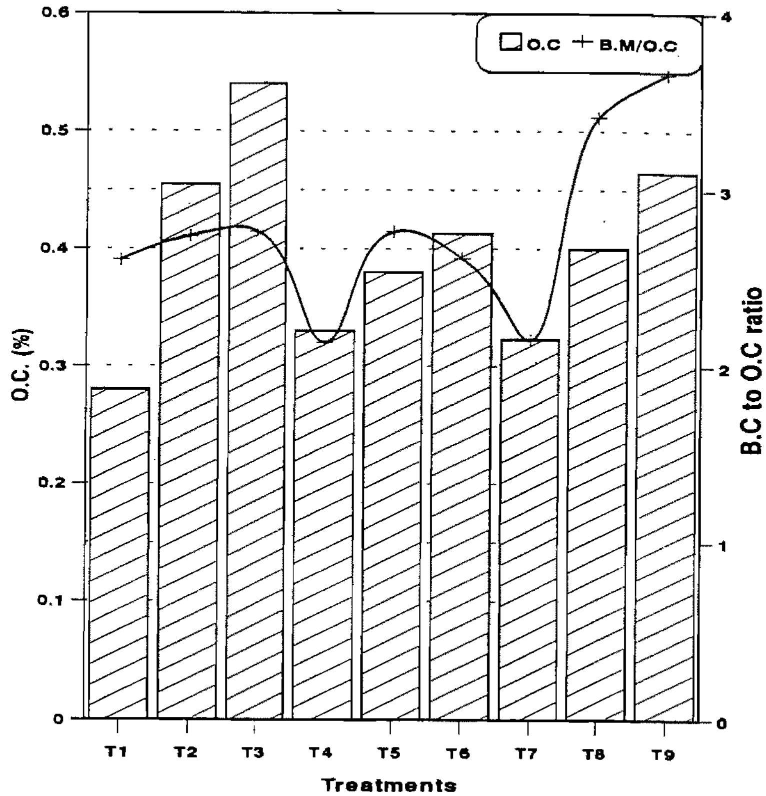
Fig. 7 indicates that cultivation increased the BMOC in all the treatments (initial value 2.00). The ratio increased with the increase in the rate of application of manures and fertilizers upto nitrogen equivalent to 120 kg ha^{-1} after which it decreased. In general, the ratio was more in the organic + inorganic fertilizer treatment. When the biomass carbon content was arranged in ascending order, it was observed that with the increase in organic carbon the BMOC increased after that the rate of increase slowed down.

4.2.13 Respiration to microbial biomass ratio

The respiration to microbial biomass ratio (RMB) during rice (Table 19) varied from 0.470 to 0.650 and 0.453 to 0.652 at 45 DAT and harvest stage, respectively. Green manuring was found to be significant at both the stages. The same trend was observed during wheat which varied from 0.320 to 0.637 and 0.448 to 0.632 at 60 DAS and harvest stage, respectively. The highest ratio was found in the soil which received inorganic fertilizer @ nitrogen equivalent to 120 kg ha^{-1} (I_{120}) and lowest in organic+inorganic @ nitrogen equivalent to 180 kg ha^{-1} ($O_{90}+I_{90}$) during rice and wheat (Fig. 8).

When the biomass carbon content of soil was arranged in ascending order (Fig. 8) which indicated that the ratio (RMB) initially increased with the increase in biomass carbon and then the increase in the ratio (RMB) slowed down with the increase in the biomass carbon content of soil. The same trend in the ratio was observed with the rate of increase in fertilizers and manures.

Fig.7 Changes in organic carbon and biomass to organic carbon ratio of soil in rice



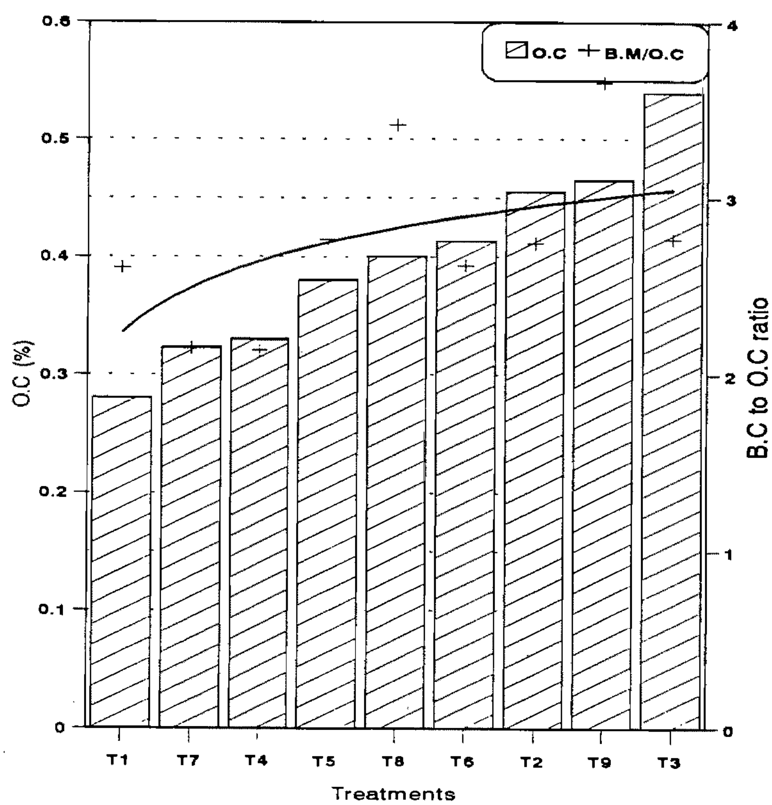


Table 19. Respiration to microbial biomass as affected by fertilizers and manurial treatments at different growth stages under rice-wheat system

	RICE					
Treatments	*+GM*	*-GM* 45 DAT	*Mean*	*+GM*	*-GM* 90 DAT (HS)	*Mean*
O_0	0.510	0.467	0.488	0.493	0.443	0.468
O_{120}	0.520	0.676	0.598	0.510	0.677	0.593
O_{180}	0.443	0.550	0.497	0.417	0.560	0.488
I_0	0.510	0.490	0.500	0.510	0.480	0.495
I_{120}	0.663	0.637	0.650	0.663	0.640	0.652
I_{180}	0.570	0.593	0.582	0.550	0.550	0.550
O_0+I_0	0.473	0.490	0.481	0.480	0.470	0.475
$O_{60}+I_{60}$	0.483	0.513	0.498	0.510	0.550	0.530
$O_{90}+I_{90}$	0.483	0.457	0.470	0.437	0.470	0.453
Mean	0.517	0.542	0.529	0.508	0.547	0.527

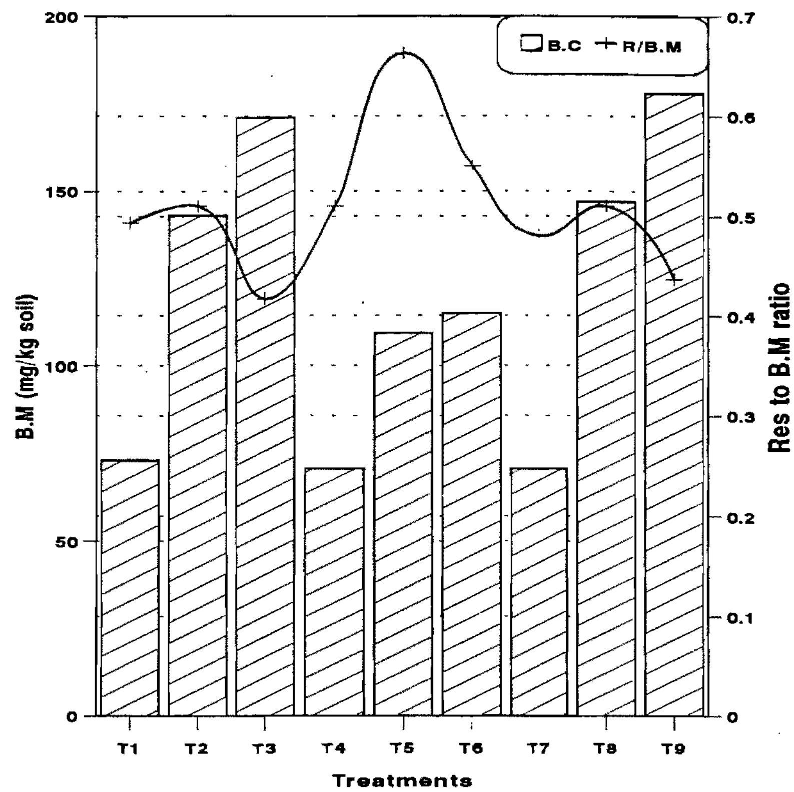
C.D (P=0.05) Manure = 0.010 C.D (P=0.05) Manure = 0.011
Treatments = 0.023 Treatments = 0.023
M x T = 0.033 M x T = 0.033

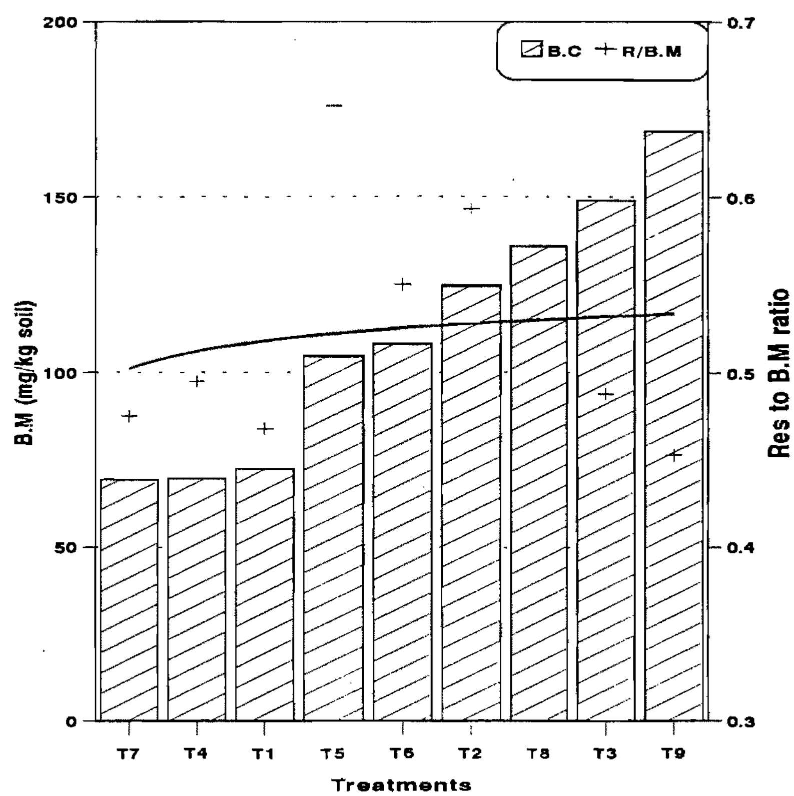
	WHEAT					
Treatments	*+GM*	*-GM* 60 DAS	*Mean*	*+GM*	*-GM* 125 DAS (HS)	*Mean*
O_0	0.510	0.520	0.515	0.493	0.453	0.473
O_{120}	0.510	0.673	0.592	0.510	0.683	0.597
O_{180}	0.447	0.550	0.498	0.463	0.550	0.507
I_0	0.500	0.500	0.500	0.500	0.450	0.475
I_{120}	0.657	0.617	0.637	0.653	0.610	0.632
I_{180}	0.550	0.570	0.560	0.573	0.560	0.567
O_0+I_0	0.510	0.490	0.500	0.520	0.487	0.503
$O_{60}+I_{60}$	0.457	0.480	0.468	0.470	0.513	0.492
$O_{90}+I_{90}$	0.380	0.460	0.320	0.397	0.500	0.448
Mean	0.502	0.540	0.521	0.509	0.534	0.521

C.D (P=0.05) Manure = 0.011 C.D (P=0.05) Manure = 0.011
Treatments = 0.023 Treatments = 0.023
M x T = 0.033 M x T = 0.032

O - Organic; I - Inorganic; O + I - Organic and Inorganic.

Fig.8 Changes in biomass carbon and respiration to microbial biomass ratio of soil in rice





4.2.14 Grain yield

The grain yield of rice and wheat is given in Table 20. The rice yield ranged from 10.0 to 29.30 g pot^{-1}. Green manuring was found to be significant in increasing the grain yield. The organic control (O_0) treatment varied significantly with inorganic control (I_0) and organic+inorganic (O_0+I_0) treatments. Further, it was observed that all the treatments comprising manures and fertilizers @ nitrogen equivalent to 120 kg ha^{-1} differed significantly with each other (O_{120}, I_{120} and $O_{90}+I_{90}$). The highest grain yield (Fig. 9a) was recorded in organic + inorgnic nitrogen equivalent to 180 kg ha^{-1} alongwith green manure and lowest in inorganic control (I_0) treatment without green manure (Fig. 9b). In general the grain yield was more in organic + inorganic followed by inorganic and organic treatments.

The wheat grain yield varied from 5.59 to 19.02 g pot^{-1}. Residual effect of green manuring was found to be significant. The highest grain yield (Fig. 10a) was recorded in organic + inorganic nitrogen equivalent to 180 kg ha^{-1} ($O_{90}+I_{90}$) along with green manure and lowest in organic control (O_0) treatment (Fig. 10b). In general the grain yield was more in organic + inorganic treatment followed by organic and inorganic treatments. Wheat yield was lower than rice yield.

Plate 1 and 2 show the effect of different fertilizers and manurial treatments on rice growth. In green manured organic treatments (Plate-1a) early maturity was noticed. In all the control treatments (Plate-1a, 1b, 1c) yellowing was noticed. Further, profused vegetative growth was prominent in inorganic treatments (Plate-1b). The same trend was observed in the treatments without green manure (Plate-2a, 2b, 2c) but the severity of nitrogen deficiency was more in control treatment.

Table 20. Grain yield (g pot[-1]) as affected by fertilizers and manurial treatments in rice-wheat system

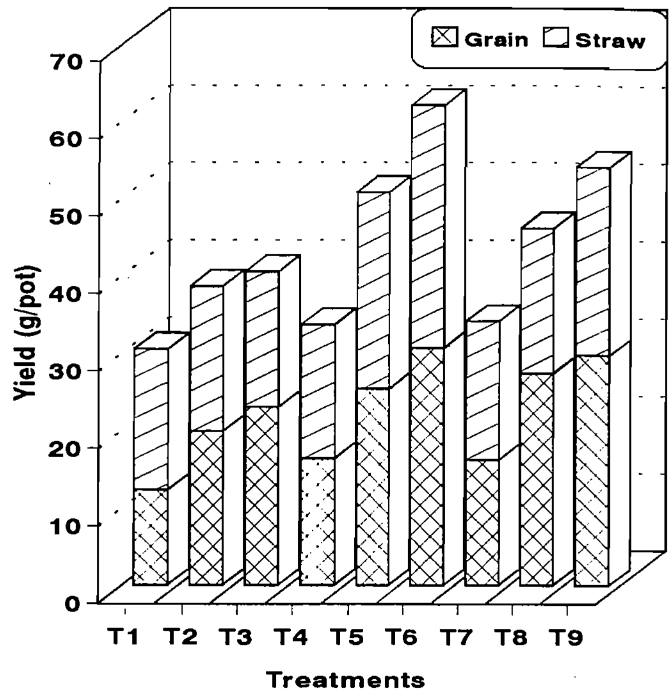
Treatments	*RICE*			*WHEAT*		
	+GM	*-GM*	*Mean*	*+GM*	*-GM*	*Mean*
O_0	12.25	7.74	10.0	5.87	5.32	5.59
O_{120}	19.85	13.19	16.52	14.95	12.15	13.55
O_{180}	22.99	20.85	21.92	18.16	17.96	18.06
I_0	16.34	6.20	11.27	6.31	6.10	6.21
I_{120}	25.33	24.28	24.81	14.00	11.10	12.55
I_{180}	30.64	27.75	29.20	19.25	15.68	17.47
O_0+I_0	16.12	6.41	11.27	6.10	5.90	6.00
$O_{60}+I_{60}$	27.33	25.16	26.25	17.60	14.75	16.18
$O_{90}+I_{90}$	29.70	28.9	29.30	20.08	17.96	19.02
Mean	22.28	17.83	20.06	13.59	11.88	12.74

C.D (P=0.05)				C.D (P=0.05)			
	Manure	=	0.234		Manure	=	0.192
	Treatments	=	0.492		Treatments	=	0.291
	M x T	=	0.695		M x T	=	0.512

O - Organic; I - Inorganic; O + I - Organic and Inorganic.
0, 120, 180 denotes N equivalent kg ha[-1].

Fig. 9. Effect of different fertilizers and manurial treatments on rice yield

a. With green manure



b. Without green manure

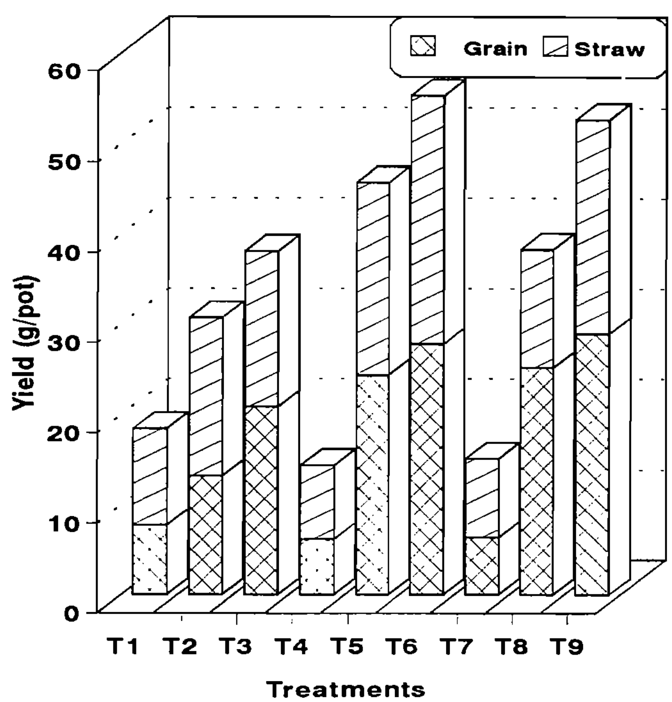
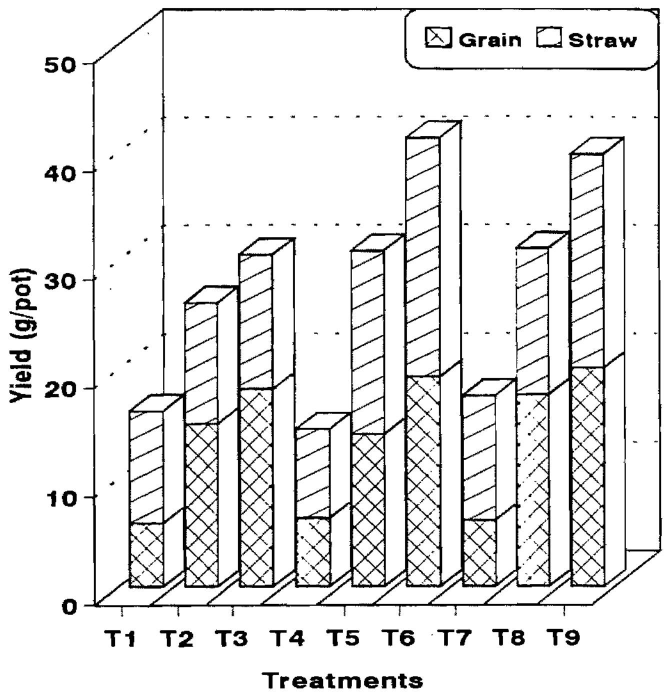
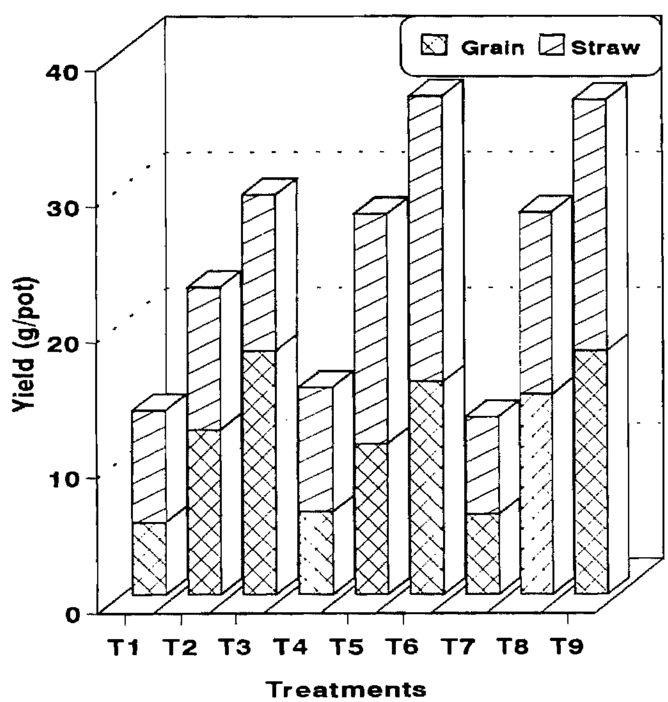


Fig. 10. Effect of different fertilizers and manurial treatments on wheat yield

a. With green manure



b. Without green manure



GM	-	Green manure
O_{N0}	-	No FYM
O_{N1}	-	FYM @ N equivalent to 120 kg/ha
O_{N2}	-	FYM @ N equivalent to 180 kg/ha
I_{N0}	-	No N fertilizer
I_{N1}	-	Inorganic fertilizer @ N equivalent to 120 kg/ha
I_{N2}	-	Inorganic fertilizer @ N equivalent to 180 kg/ha
$O+I_{N0}$	-	No N fertilizer
$O+I_{N1}$	-	Organic + Inorganic fertilizer @ N equivalent to 60 kg/h
$O+I_{N2}$	-	Organic + Inorganic fertilizer @ N equivalent to 90 kg/h

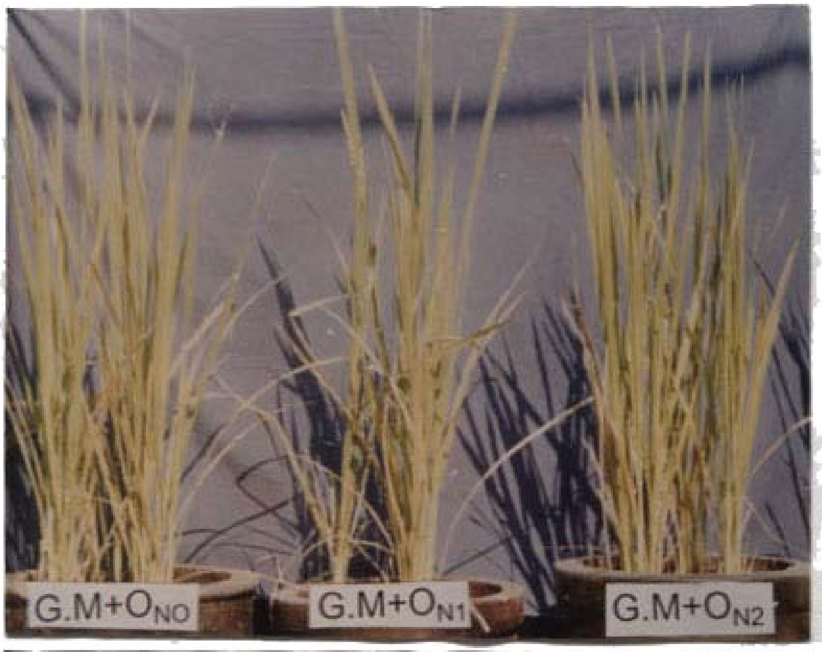


Plate-1a. Organic

Plate-1b. Inorganic

Plate-1c.
Organic + Inorganic

Plate 1. Effect of fertilizers and manurial treatment on rice with green manure

Plate-2a. Organic

Plate-2b. Inorganic

Plate-2c.
Organic - Inorganic

Plate 2. Effect of fertilizers and manurial treatment on rice without green manure

Plate-3a. Organic

Plate-3b. Inorganic

Plate-3c.
Organic - Inorganic

Plate 3. Effect of fertilizers and manurial treatment on wheat with green manure

Plate-4a Organic

Plate-4b. Organic - Inorganic

Plate 4. Effect of fertilizers and manurial treatment on wheat without green manure

Plate 3 and 4 show the effect of different manures and fertilizers on wheat yield. The growth and yield appeared to be equal in green manured organic and inorganic treatments. Increase in yield with rate of increase in manures and fertilizers was evident in all the treatments. Better growth was seen (Plate-3c) in green manured, organic + inorganic treatment (G.M+O+I_{N2}).

Field experiment

Soil samples were collected from different locations with rice-wheat cropping system in Karnal district of Haryana. The locations varied widely in their fertility status, intensity of cultivation, management and duration of rice-wheat cropping system.

4.3 Soil quality indicators

The soil samples collected from the field were analysed for the soil quality indicators and the results are presented below.

4.3.1 Soil reaction

The initial pH of soil samples (Table 21) collected from different locations under rice-wheat system varied from 7.52 to 8.90. At harvest stage of rice, pH of soil at different locations was found to have lower pH than the initial values and it varied from 7.50 to 8.50. However, at wheat harvest the pH was more than it was during rice. The higher pH was recorded at L17 and lowest at L1 and L2 during rice and wheat. In general it was observed that the pH of the soil was slightly saline to alkaline in reaction and decreased after rice and again increased during wheat harvest stage but lower than the initial value.

Table 21. Changes in pH of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	7.52	7.50	7.51
L2	7.54	7.50	7.51
L3	7.81	7.72	7.78
L4	7.88	7.74	7.85
L5	7.84	7.73	7.82
L6	7.85	7.74	7.82
L7	8.90	8.50	8.81
L8	8.29	8.00	8.21
L9	8.12	7.96	8.00
L10	8.00	7.90	7.97
L11	8.05	7.88	7.80
L12	7.80	7.74	8.34
L13	7.65	7.75	8.31
L14	8.36	8.16	8.25
L15	8.39	8.11	8.23
L16	8.20	7.92	8.01
L17	8.28	7.98	8.08

4.3.2 EC

The initial EC of soil samples (Table 22) collected from different locations under rice-wheat system ranged from 0.20 to 0.41 dSm^{-1}. During harvest of rice EC of soil varied from 0.20 to 0.40 dSm^{-1}, and it was found to be lower than the initial EC of soils. But, after the harvest of wheat EC again increased, and it ranged from 0.20 to 0.42 dSm^{-1}. The lowest EC was recorded at L2 and highest at L11 during rice and wheat. However, EC at harvest stage of wheat was lower than initial values.

4.3.3 Bulk density

In general, the bulk density of the soil samples (Table 23) didn't vary much during rice-wheat. The bulk density values varied from 1.292 to 1.388 Mg m^{-3} in the initial soil samples from 1.296 to 1.388 Mg m^{-3} at rice harvest stage and from 1.296 to 1.391 Mg m^{-3} at wheat harvest stage. The lowest bulk density was found at L3.

4.3.4 Organic carbon

The organic carbon content (Table 24) of soil samples varied from 0.26 to 0.53, 0.27 to 0.56 and 0.26 to 0.56 % at initial, at rice harvest and at wheat harvest stages, respectively. The lowest organic carbon content was found at L17 and highest at L4 during rice and wheat. In general, cultivation either maintained or increased the soil organic carbon content at different locations.

4.3.5 Total nitrogen

The total nitrogen content (Table 25) was influenced by intensity of cultivation and application of fertilizers and manures. At initial stage it ranged from 696 to 814 mg kg^{-1} soil. The lowest was observed at L17 and

Table 22. Changes in EC (dSm^{-1}) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	0.25	0.23	0.24
L2	0.20	0.20	0.20
L3	0.23	0.20	0.22
L4	0.27	0.24	0.25
L5	0.26	0.25	0.25
L6	0.30	0.28	0.29
L7	0.41	0.38	0.38
L8	0.35	0.30	0.31
L9	0.32	0.30	0.31
L10	0.30	0.29	0.29
L11	0.41	0.40	0.42
L12	0.28	0.25	0.38
L13	0.27	0.25	0.40
L14	0.35	0.37	0.39
L15	0.38	0.38	0.32
L16	0.39	0.37	0.37
L17	0.33	0.32	0.32

Table 23. Changes in Bulk density (Mgm^{-3}) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	1.338	1.340	1.343
L2	1.304	1.307	1.308
L3	1.292	1.296	1.296
L4	1.386	1.386	1.388
L5	1.358	1.360	1.364
L6	1.384	1.388	1.391
L7	1.375	1.376	1.376
L8	1.339	1.340	1.342
L9	1.334	1.338	1.343
L10	1.314	1.316	1.321
L11	1.346	1.349	1.352
L12	1.388	1.380	1.357
L13	1.359	1.368	1.372
L14	1.350	1.354	1.374
L15	1.366	1.370	1.364
L16	1.373	1.372	1.369
L17	1.362	1.363	1.363

Table 24. Changes in Organic Carbon (%) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	0.46	0.49	0.52
L2	0.47	0.50	0.51
L3	0.52	0.56	0.56
L4	0.53	0.53	0.55
L5	0.40	0.43	0.47
L6	0.41	0.45	0.49
L7	0.40	0.41	0.41
L8	0.38	0.39	0.42
L9	0.42	0.46	0.52
L10	0.39	0.41	0.46
L11	0.37	0.40	0.43
L12	0.53	0.51	0.39
L13	0.41	0.44	0.37
L14	0.31	0.36	0.30
L15	0.30	0.35	0.28
L16	0.29	0.28	0.29
L17	0.26	0.27	0.26

highest at L12. At rice harvest and wheat harvest stage it varied from 702 to 812 and 698 to 820 mg kg^{-1} soil, respectively. In both the cases, the lowest was observed at L17 and the highest at L3. At L14 to L17 total nitrogen increased at rice harvest and decreased at wheat harvest. At L7 and L13 total nitrogen content decreased due to cultivation and at all other location it increased after rice and wheat.

4.3.6 Available nitrogen

The available nitrogen content of soil samples at different locations (Table 26) varied from 66 to 120, 65 to 125 and 64 to 127 mg kg^{-1} soil at initial and at harvest of rice and wheat, respectively. During rice-wheat the lowest available nitrogen content was observed at L7 and the highest at L9. During rice-wheat there was no marked trend in available nitrogen content of the soils.

4.3.7 Available phosphorus

The available phosphorus content is given in Table 27 and the results indicated that it varied from 13.0 to 19.3, 12.9 to 20.0 and 13.0 to 21.6 mg kg^{-1} soil at initial, at harvest of rice and wheat, respectively. The lowest available phosphorus was found at L17 during rice-wheat. In general, there was a positive balance of available phosphorus in soil except at L14 and L15.

4.3.8 Available potassium

The available potassium content as given in Table 28, varied from 240 to 310. 242 to 312 and 238 to 310 mg kg^{-1} soil at initial. at harvest of rice and wheat, respectively. The lowest available potassium was observed at L17 and highest at L3 during rice-wheat. At wheat harvest it increased

Table 25. Changes in total nitrogen (mg kg^{-1} soil) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	790	792	800
L2	794	794	797
L3	809	812	820
L4	810	809	811
L5	773	776	786
L6	776	785	790
L7	776	770	765
L8	745	760	781
L9	769	781	798
L10	748	770	782
L11	738	762	780
L12	814	810	756
L13	778	775	740
L14	722	743	718
L15	711	728	702
L16	703	708	702
L17	696	702	698

Table 26. Changes in available nitrogen (mg kg^{-1} soil) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	113	120	115
L2	115	124	120
L3	115	117	118
L4	110	114	115
L5	104	103	112
L6	97	99	103
L7	66	65	64
L8	73	70	73
L9	120	125	127
L10	110	110	112
L11	108	110	113
L12	111	118	90
L13	106	105	88
L14	89	89	96
L15	88	86	86
L16	94	91	94
L17	87	82	81

Table 27. Changes in available phosphorus (mg kg^{-1} soil) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	15.7	15.7	16.1
L2	15.9	16.0	16.1
L3	18.7	19.1	19.7
L4	16.1	16.8	17.1
L5	16.0	16.8	17.0
L6	16.6	16.6	16.8
L7	15.8	16.0	16.5
L8	16.1	16.3	16.9
L9	19.3	19.9	21.6
L10	17.8	18.8	19.8
L11	19.1	20.0	20.2
L12	16.2	16.7	16.5
L13	16.1	16.9	16.2
L14	14.2	15.3	13.3
L15	14.7	15.8	13.0
L16	13.1	13.3	13.2
L17	13.0	12.9	13.0

Table 28. Changes in available potassium (mg kg^{-1} soil) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	295	298	301
L2	298	299	299
L3	310	312	310
L4	300	308	306
L5	301	306	304
L6	298	305	305
L7	281	290	288
L8	286	289	293
L9	296	303	301
L10	294	298	298
L11	291	293	290
L12	296	309	273
L13	305	307	270
L14	271	274	247
L15	268	269	239
L16	247	248	240
L17	240	242	238

when compared to initial value from L1 to L10 and decreased from L12 to L17.

4.3.9 Biomass carbon

The biomass carbon content of soil (Table 29) at initial, at harvest of rice and wheat ranged from 52 to 89, 78 to 155 and 79 to 161 mg kg^{-1} soil, respectively. The results indicated that cultivation increased the biomass carbon content and it is influenced more by cultivation practices at lower fertility levels.

4.3.10 Respiration

The respiration of soil (Table 30) varied from 34 to 53, 49 to 78 and 45 to 80 mg CO_2-C kg^{-1} 24 h^{-1} at initial, at harvest of rice and wheat, respectively. Respiration increased due to cultivation and there was no definite trend in respiration during rice-wheat.

4.3.11 Dehydrogenase activity (DHA)

The results of DHA (Table 31) indicated that it varied from 60 to 98, 68 to 110 and 63 to 114 μg TPF g^{-1} soil 24 h^{-1} at initial, at harvest of rice and wheat, respectively. The DHA after wheat harvest was more than that of initial stage. The highest DHA was observed at L3 and lowest at L16 and L17 during rice-wheat.

4.3.12 Biomass to organic carbon ratio

During rice-wheat the ratio (Table 32) varied from 1.45 to 2.00, 1.95 to 2.98 and 2.17 to 3.21 at initial, at harvest of rice and wheat, respectively. In general, the ratio increased at harvest stage of wheat. The lowest value

Table 29. Changes in biomass carbon (mg kg^{-1} soil) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	85	120	130
L2	86	122	137
L3	89	135	158
L4	86	155	161
L5	64	108	102
L6	68	110	110
L7	58	80	96
L8	64	108	113
L9	75	116	126
L10	62	106	105
L11	60	94	100
L12	85	152	98
L13	66	110	97
L14	56	95	92
L15	56	80	90
L16	55	80	79
L17	52	78	80

Table 30. Changes in respiration (mg CO_2-C kg^{-1} soil 24 h^{-1}) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	46	68	70
L2	48	72	72
L3	50	78	80
L4	52	74	77
L5	44	65	63
L6	45	64	62
L7	43	62	65
L8	38	57	59
L9	44	65	66
L10	35	56	58
L11	34	51	54
L12	53	77	58
L13	46	68	53
L14	37	59	52
L15	38	53	51
L16	36	50	47
L17	35	49	45

Table 31. Changes in DHA (μg TPF g^{-1} soil 24 h^{-1}) of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	86	98	99
L2	91	103	110
L3	98	110	114
L4	96	108	109
L5	80	90	98
L6	82	94	98
L7	81	89	90
L8	74	85	84
L9	83	92	90
L10	71	80	81
L11	70	78	81
L12	96	110	79
L13	83	90	78
L14	68	75	76
L15	66	75	70
L16	61	70	63
L17	60	68	67

Table 32. Changes in biomass carbon to organic carbon of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	1.85	2.45	2.50
L2	1.83	2.44	2.69
L3	1.71	2.41	2.82
L4	1.62	2.92	2.93
L5	1.60	2.51	2.17
L6	1.66	2.44	2.24
L7	1.45	1.95	2.34
L8	1.68	2.77	2.69
L9	1.79	2.52	2.42
L10	1.59	2.59	2.28
L11	1.62	2.35	2.33
L12	1.60	2.98	2.51
L13	1.61	2.50	2.62
L14	1.81	2.64	3.07
L15	1.87	2.29	3.21
L16	1.90	2.86	2.72
L17	2.00	2.89	3.08

(1.45) was observed during initial stage at L7 and highest during harvest stage of wheat at L15.

4.3.13 Respiration to microbial biomass ratio

The respiration to microbial biomass ratio (Table 33) during rice-wheat ranged from 0.54 to 0.74, 0.48 to 0.78 and 0.48 to 0.68 at initial and at harvest of rice and wheat, respectively. In general, at initial stage the ratio was higher and decreased at harvest stage of wheat. The highest ratio was observed at L7.

4.4 Soil quality indices

Data obtained from pot culture experiment and field experiment with rice-wheat cropping system were used to compute soil quality indices. Three methods to compute soil quality index (details are given in Chapter-3.4) have been used and the results are presented below.

4.4.1 Changes during pot culture experiment

The results (Table 34) indicated that, in general, soil quality index was high due to green manuring in all the three methods used. Increase in the rate of manures and fertilizers had increased the soil quality indices. The organic control treatment (O_0) was found to have lower value. Methods I and II gave the same trend, however they differed in the degree of sensitivity to reflect the changes under rice-wheat system. Method-III gave highly fluctuating values and showed decrease in soil quality index values at wheat harvest stage in all the treatments.

Using method-I, the highest soil quality index value was observed in organic + inorganic nitrogen equivalent to 180 kg ha^{-1} along with green manure (O_{90}+I_{90}) and lowest in organic control (O_0) treatment. In general,

Table 33. Changes in respiration to microbial biomass of soil in rice-wheat field at different locations

Location	*Initial*	*90 DAT of Rice (HS)*	*125 DAS of Wheat (HS)*
L1	0.54	0.57	0.54
L2	0.56	0.59	0.53
L3	0.56	0.58	0.51
L4	0.60	0.48	0.48
L5	0.69	0.60	0.62
L6	0.66	0.58	0.56
L7	0.74	0.78	0.68
L8	0.59	0.53	0.52
L9	0.59	0.56	0.52
L10	0.56	0.53	0.55
L11	0.57	0.54	0.54
L12	0.62	0.51	0.59
L13	0.70	0.62	0.55
L14	0.66	0.62	0.57
L15	0.68	0.66	0.57
L16	0.65	0.63	0.59
L17	0.67	0.63	0.56

Table 34. Soil quality indices of rice-wheat cropping system as affected by fertilizers and manurial treatments in pot culture experiment

Treatments	Method-I		Method-II		Method-III	
	After rice	After wheat	After rice	After wheat	After rice	After wheat
$G.M+O_0$	1.846	1.846	1.909	1.050	1.899	1.009
$G.M+O_{120}$	2.128	2.385	1.960	1.708	1.948	1.658
$G.M+O_{180}$	2.308	2.462	2.829	1.997	2.837	1.944
$G.M+I_0$	1.897	1.872	1.923	1.053	1.913	1.014
$G.M+I_{120}$	2.282	2.308	2.845	1.141	2.835	1.092
$G.M+I_{180}$	2.333	2.333	2.839	2.052	2.853	2.006
$G.M+O_0+I_0$	1.846	1.949	1.909	1.078	1.899	1.038
$G.M+O_{60}+I_{60}$	2.385	2.462	2.844	1.692	2.827	1.641
$G.M+O_{90}+I_{90}$	2.487	2.513	2.841	1.999	2.847	1.946
O_0	1.718	1.718	1.048	1.042	1.038	1.003
O_{120}	2.128	2.077	1.971	1.127	1.960	1.081
O_{180}	2.308	2.359	2.007	2.054	2.019	2.007
I_0	1.923	1.872	1.949	1.053	1.938	1.014
I_{120}	2.154	2.205	2.816	1.135	2.806	1.092
I_{180}	2.205	2.308	2.821	1.747	2.827	1.703
O_0+I_0	1.897	1.821	1.935	1.049	1.925	1.012
$O_{60}+I_{60}$	2.385	2.256	2.856	1.398	2.839	1.351
$O_{90}+I_{90}$	2.359	2.308	2.823	1.987	2.831	1.937

G.M - Green manure; O - Organic; I - Inorganic; O + I - Organic and inorganic
0, 120, 180 denotes N equivalent kg ha^{-1}
Initial value for the soil used in the potculture experiment (method-I) = 1.923.

during rice-wheat the highest value was observed in organic + inorganic treatments followed by inorganic and organic except control treatments.

The changes in soil quality index (using method-I) is given in Fig. 11. It indicated that in control treatments, there were negative impact on soil quality index. However, greater positive changes in the index value was observed due to green manuring.

4.4.2 Changes during field experiment

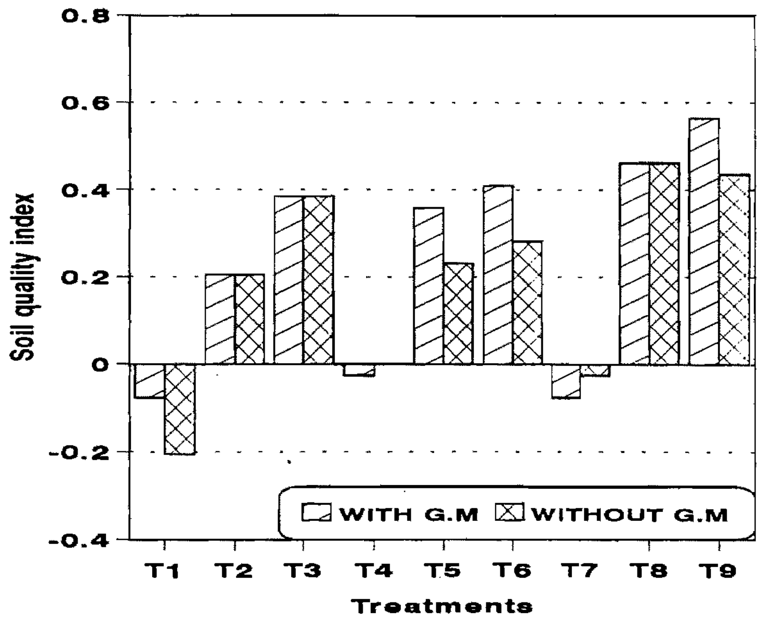
The soil quality indices for rice-wheat cropping system, using three methods are given in Table 35. It indicated that the index (using method-I) varied from 2.000 to 2.385 at different locations. The highest value was observed at L3 at initial stage and at rice harvest and at L1 and L2 at wheat harvest. In general, lowest values were observed at L3 and from L13 to L17. However, index value obtained using method-III showed fluctuation during rice-wheat. There were net negative changes (Fig. 12) at L4, at rice harvest and at L3, L8, L12, L16 and L17 at wheat harvest. At location L1 there was greater positive change after rice and wheat.

4.5 Sustainability of rice-wheat system

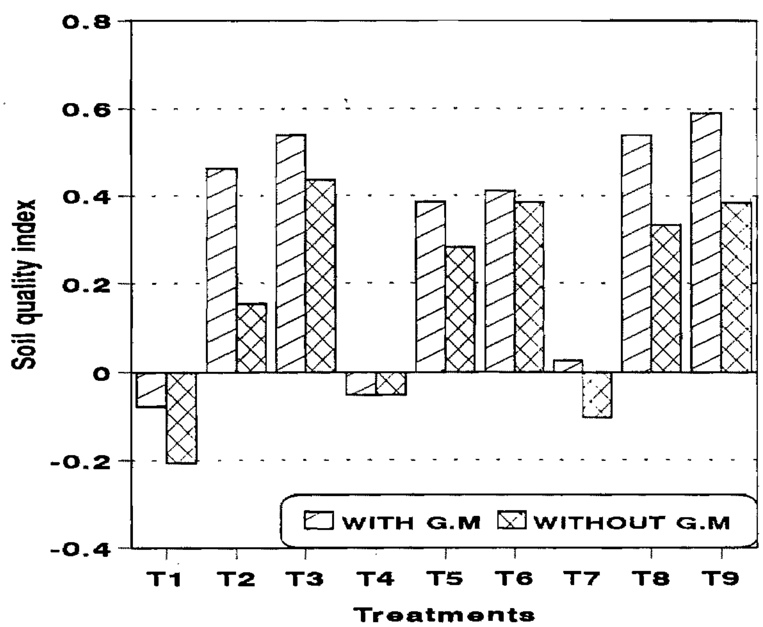
Sustainability of rice-wheat system was monitored using soil quality index. All the three methods were used to calculate the soil quality index, for all the soil samples (L1 to L17) collected from Karnal. Soil quality index over a period of time (during rice-wheat) along with initial value was used to compute the trend which in turn indicated the sustainability of the rice-wheat system. The sustainability of rice-wheat was monitored using methods I and II for locations 1, 5 and 8 (Fig. 13). Both the methods gave the

Fig. 11. Changes in soil quality index as affected by different fertilizers and manurial treatments

a. After rice



b. After wheat

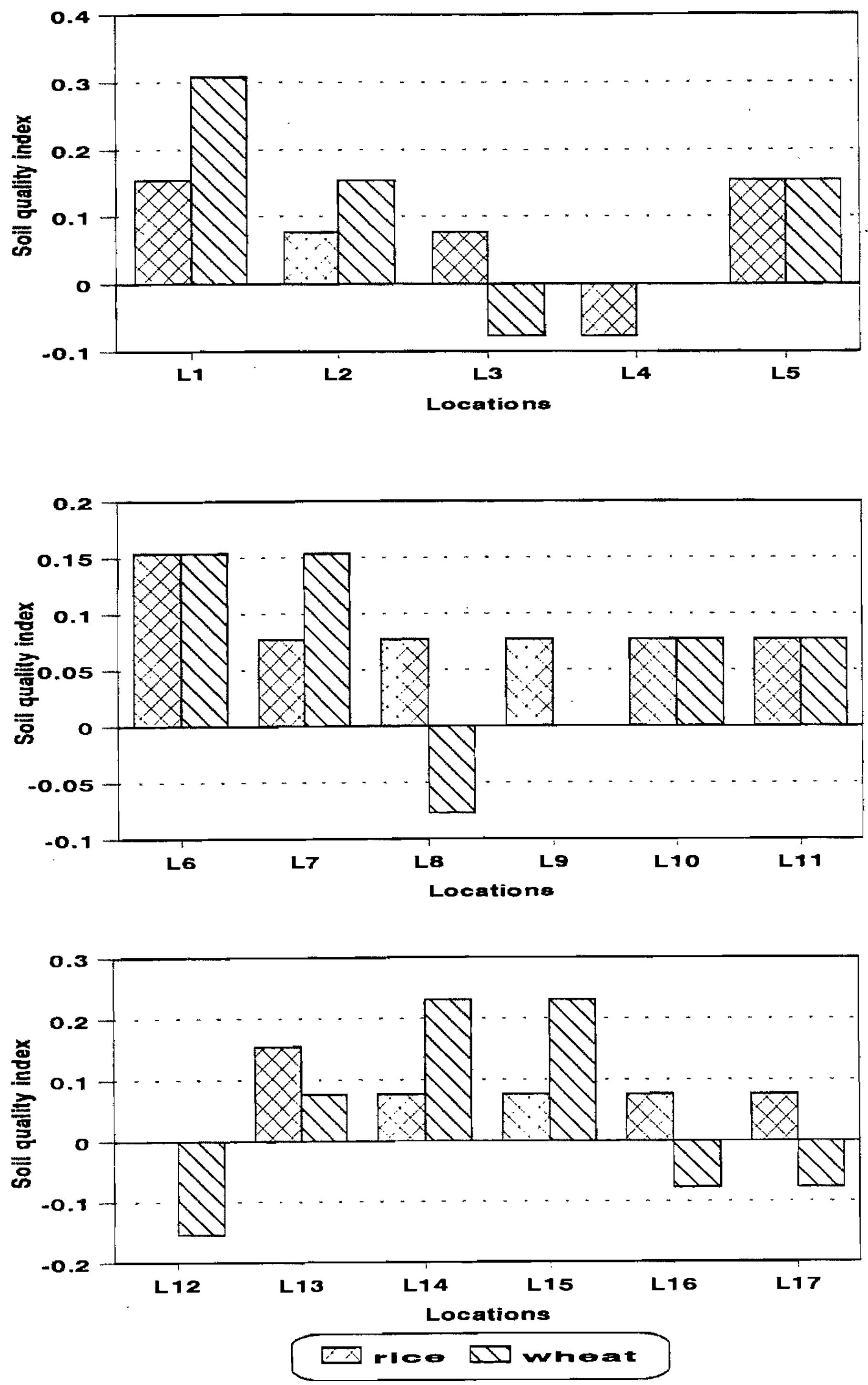


Changes are calculated by substracting initial index value from values obtained after rice and wheat using method-I

Table 35. Soil quality indices in rice-wheat cropping system at different locations

Location	Method-I			Method-II			Method-III		
	Initial	After rice	After wheat	Initial	After rice	After wheat	Initial	After rice	After wheat
L1	2.154	2.308	2.462	2.454	2.717	2.771	2.418	2.673	2.378
L2	2.308	2.385	2.462	2.500	2.749	2.771	2.423	2.679	2.378
L3	2.385	2.462	2.308	2.524	2.241	2.720	2.476	2.208	2.376
L4	2.231	2.154	2.231	2.477	2.011	2.694	2.399	1.944	2.371
L5	2.000	2.154	2.154	2.407	2.115	2.557	2.380	2.102	2.221
L6	2.000	2.154	2.154	2.407	2.115	2.557	2.380	2.102	2.221
L7	1.923	2.000	2.077	2.383	1.513	2.531	2.359	1.531	2.217
L8	2.000	2.077	1.923	2.407	2.084	2.354	2.380	2.102	2.065
L9	2.154	2.231	2.154	2.454	2.147	2.669	2.401	2.103	2.370
L10	2.000	2.077	2.077	2.407	2.084	2.405	2.380	2.102	2.069
L11	2.000	2.077	2.077	2.407	2.084	2.405	2.380	2.102	2.069
L12	2.231	2.231	2.077	2.477	2.043	2.405	2.399	1.944	2.069
L13	2.000	2.154	2.077	2.407	2.115	2.405	2.380	2.102	2.069
L14	2.000	2.077	2.231	2.407	2.084	2.456	2.380	2.102	2.087
L15	2.000	2.077	2.231	2.407	2.084	2.456	2.380	2.102	2.087
L16	2.000	2.077	2.077	2.407	2.084	2.405	2.380	2.102	2.069
L17	2.000	2.077	2.231	2.407	2.084	2.456	2.380	2.102	2.087

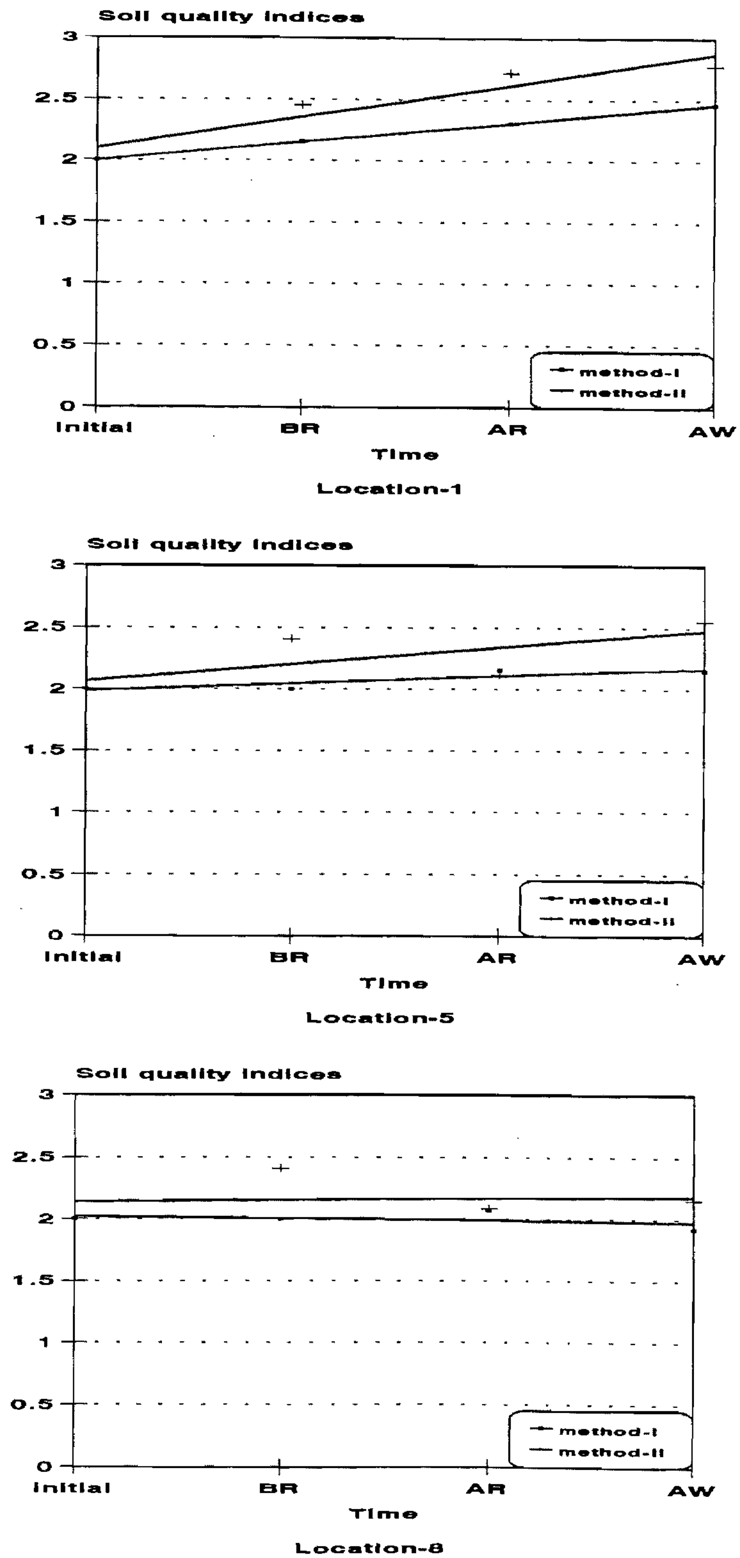
Fig. 12. Sustainability of rice-wheat as measured by changes in soil quality index at different locations



Changes are calculated by substracting initial index value from values obtained after rice and wheat using method-I same trend but, their sensitivity differed. Method-II seems to be sensitive to changes in rice-wheat system that is evident from Fig. 13 and Table 35.

Method-I was used to monitor the sustainability of the rice-wheat system (Fig. 14). Different trends in soil quality index were observed for different locations in Karnal. From the diagram it is observed that the rice-wheat cropping system is aggrading at location-1, sustaining at location-13 and degrading at location-8.

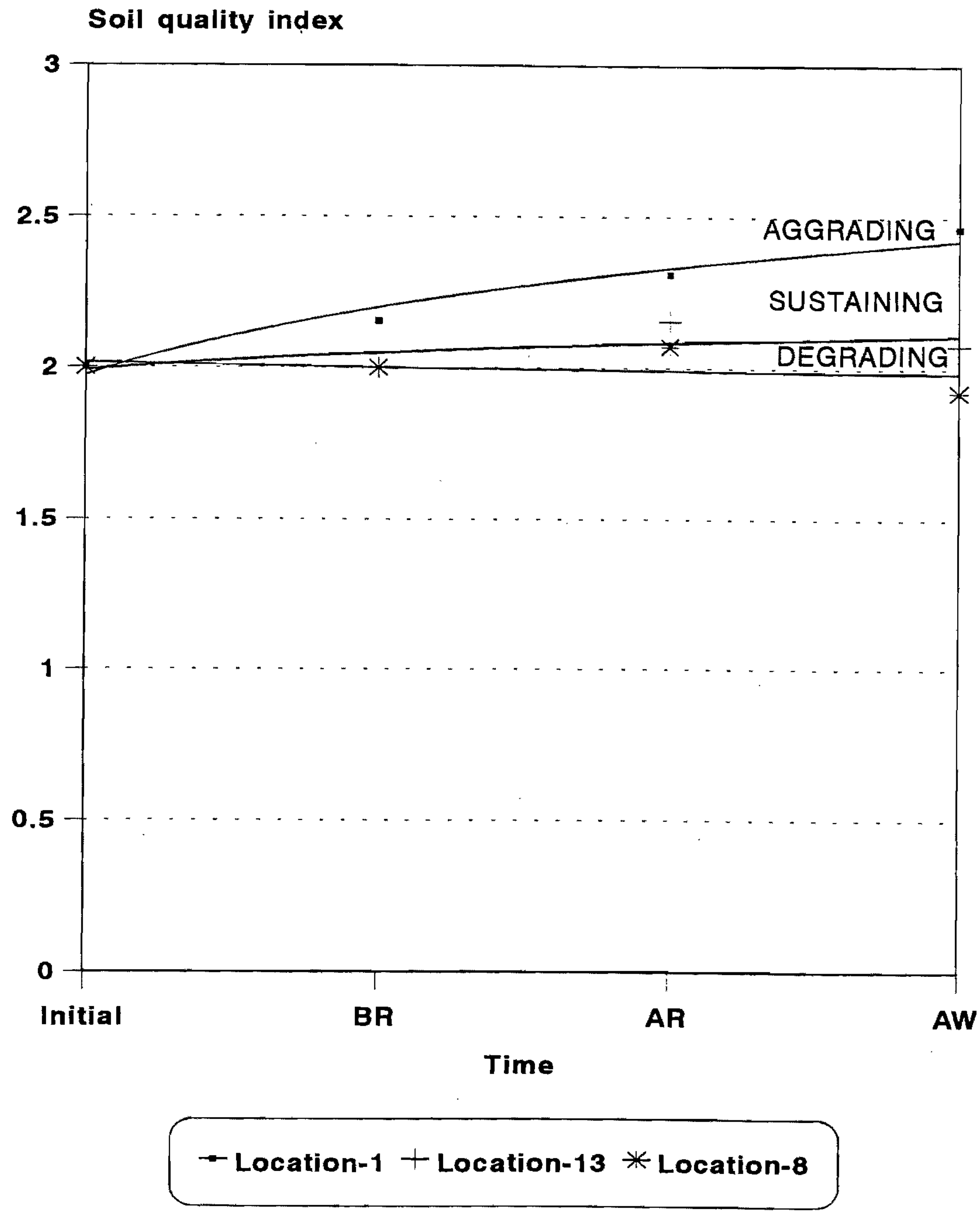
Fig. 13. Monitoring trends in soil quality indices in rice-wheat cropping system at different locations



BR-before rice; AR-after rice; AW-After wheat

Initial sample was collected 3 years before in a rice-wheat field

Fig.14 Monitoring trends in soil quality index in rice-wheat cropping system at different locations



BR-Before rice; AR-After rice; AW-After wheat

DISCUSSION

5.1 Characteristics of experimental soil

Contrasting edaphic requirements of rice and wheat grown in sequence on the same piece of land calls for special management practices. Hence, the soil properties in rice-wheat vary at different stages. Maintaining the productivity of both the crops in sequence over a period of time is a challenging task. The initial soil (Table 6) used in pot culture experiment was slightly alkaline in reaction and low in salt content. The bulk density was low because of high clay and moderate organic matter content. The soil had lower available nitrogen and moderate phosphorus and potassium possibly due to removal of nutrients by rice and wheat. Lower respiration, dehydrogenase activity of the initial soil might be due to dryness of soil at the time of sampling (after rice harvest).

5.2 Soil quality indicators in pot culture experiment

Soil quality is inferred from measuring changes in its attributes called indicators. Further, only a core set of indicators which are sensitive to changes in soil, encompassing physical, chemical and biological properties are used to assess the soil quality (Larson and Pierce, 1991). Changes in these soil quality indicators can be used to monitor the sustainability.

The pH of soil after 45 DAT of rice was lower than the initial pH (Table 7). The same trend was noticed during wheat, however, it was more than the pH during rice. This can be attributed to the effect of flooding, partial pressure of CO_2 through CO_3-HCO_3 equilibria (Ponnamperuma, 1972). Application of green manure to rice decreased the pH possibly due to production of organic acids upon decomposition. Sarkar *et al.* (1988) reported decrease in pH due to organic matter addition to rice-wheat. Among various treatments, organic+inorganic treatments during rice-wheat was found to have lower pH than other treatments. This can be explained by the fact that addition of inorganic fertilizers along with organic manures enhanced the decomposition and release of organic acids.

Electrical conductivity (EC) of soil (Table 8) was more at harvest stage (both during rice and wheat) due to the decomposition of organic materials and release of soluble salts. The same can be attributed to explain the significant difference in EC due to green manuring to rice and its residual effect during wheat. When compared to the initial soil EC, in all the treatments, EC was found to be lower. The same trend was observed by Thind and Chahal (1987) and Katyal (1977). Among the control treatments the highest EC observed in organic treatment may be due to less plant growth and as a result of this, reduction in the removal of salts from soil.

Bulk density can be used to know the aeration status of soil. Application of organic manures to soil reduces the bulk density and increases the porosity, thus making the soil environment congenial for plant root growth. The same effect was observed in green manured treatments (Table 9) during rice-wheat. The bulk density of soil was lower at 45 DAT of rice than at harvest stage due to addition of organic materials and the higher bulk density during wheat was due to decomposition of added materials. As a result of puddling of soil for rice under field conditions, the soil permeability and post infiltration drainage get reduced and the soil remains wet for longer periods. If the soil is not loosened, the crop following rice is likely to suffer from poor soil aeration following heavy rain and or irrigation (Bopari *et al.*, 1992;

Bhagat *et al.*, 1994). The effect of poor aeration was reflected during wheat, as lower growth and yield, in the treatments without green manure or organic manures (Plates 3b, 4a & 4b). This view can be supported from the observation of Meelu *et al.* (1979) that more than twice the amounts of roots were found under maize-wheat than with rice-wheat. Bulk density of soil is influenced by organic matter and clay content of soil (Brar, 1991). The same effect was found in this experiment as the bulk density of soil was negatively correlated with the organic carbon content in soil.

Maintaining the quality of soil organic matter is a critical component of soil productivity. The level of organic matter in soil is considered to be a good function of the net input of organic residues by the cropping system (Gregorich *et al.*, 1994). Green manuring for four years appreciably increased the organic carbon content in the soil profile (Swarup, 1991). The same effect was observed in the present study also, with green manuring (Table 10). During rice-wheat, green manuring increased organic carbon significantly, obviously the effect was more with organic manures. Except control treatments, cultivation increased organic carbon due to green manuring, organic manures, crop residues and roots incorporated into the soil. In organic and organic+inorganic treatments, organic carbon was more during crop growth than at harvest stage due to organic manure addition. But reverse was observed in inorganic treatments, possibly due to fast decomposition of organic matter during crop growth and addition of crop residues and roots into soil after the harvest of rice and wheat. Organic carbon content in soil during rice-wheat followed in the order of Organic > Organic + Inorganic > Inorganic, respectively. In control treatments the organic carbon content was lower than initial value, which envisages that under tropical conditions, judicious application of organic manures periodically is essential for improving and maintaining organic matter status of the soils.

The nitrogen content of plant material is an important factor controlling the rate of decomposition and nitrogen mineralisation. Total nitrogen content of soil is important. as it is essential to retain organic carbon in soil and supply of nitrogen by mineralisation. However, most of the total soil nitrogen is in organic form and only 2-3% of total nitrogen in soil is mineralised per year and hence, avoids nitrogen losses from soil. Application of green manure significantly increased the total nitrogen (Table 11) as the plant material added had high total nitrogen. The total nitrogen increased nearly in the same proportion as organic carbon. Increase in total nitrogen of coarse texture soil was also observed due to green manuring by Meelu *et al.* (1994). Total nitrogen increased with increase in the rate of manures and fertilizers application evidently due to more nitrogen addition into the soil during rice-wheat. This is in line with the results reported by Kukreja *et al.* (1991). Positive residual effect was also observed due to retention of nitrogen in soil, in the form of organic matter. Total nitrogen at maturity was lower than at crop growth stages, possibly due to mineralisation of soil nitrogen and subsequent crop removal. The total nitrogen content in soil followed the order : Organic > Organic + Inorganic > Inorganic

Mandal *et al.* (1991) also reported that total nitrogen decreased due to continuous cropping for 14 years except the plots treated with FYM. Hence, intensive cropping with rice-wheat necessitates the application of organic manures to maintain the soil nitrogen level.

Green manure, by virtue of the large amounts of readily decomposable organic matter contained in them, dictate transformation of several plant nutrients in the soil, by altering the physico-chemical properties of the soil. Nitrogen and other nutrients contained in the green manure are converted into plant available forms in the soil through the process of mineralisation. However, the kinetics of nitrogen mineralisation can differ under aerobic and anaerobic conditions. Application of green manure had significant effect on available nitrogen, during crop growth stages (Table 12). This was due to the nitrogen from green manures being rapidly mineralised for absorption by plants. In flooded fields under tropical conditions as much as 80% of green manure nitrogen can be mineralised within 2 weeks of its incorporation (Singh *et al.*, 1992). Due to crop removal and losses, available nitrogen content was low at harvest stage. The higher available nitrogen in green manured treatments may be due to lower nitrogen losses from green manure than with equivalent quantities of fertilizer nitrogen. This supports the low negative balance observed in some of the treatments.

The higher negative balance was observed (Fig. 1) in control treatments due to removal of available nitrogen from soil by crops. The residual effect of green manure on available nitrogen was in the order : Organic > Organic + Inorganic > Inorganic because of slow release of nitrogen to crop over a period of time and lower nitrogen losses in the same order.

Green manure when incorporated into the soil, decompose and through mineralisation phosphorus is released in available forms (Bin, 1983). The availability of phosphorus increased both under laboratory (Blair and Boland, 1978; Singh *et al.*, 1981; Singh *et al.*, 1988) and field conditions (Chatterjee *et al.*, 1979: Yadav and Singh, 1986). Application of green manure increased the available phosphorus (Table 13) significantly both during rice and wheat and at all the stages. This may be due to the mechanisms of reduction, chelation and favourable changes in soil pH.

Phosphorus content of the added organic matter is the most important factor in regulating the mineralisation of phosphorus from green manure and in turn availability of phosphorus. Hence, increase in rate of manures and fertilizers along with phosphatic fertilizers increased the available phosphorus in soil. This is evident from the organic control (O_0) teatment which received no phosphatic fertilizer during rice-wheat contained low in available phosphorus.

With green manure positive balance in available phosphorus (Fig. 2a) was observed. Singh and Rai (1975) and Bajpai *et al.* (1980) have also reported slightly greater build-up of inorganic phosphorus due to green manuring. However, the balance was low without green manure and negative in organic control (O_0) treatment due to no phosphatic fertilizer addition (Fig. 2b).

Green manure plants possess a strong ability to absorb the difficultly available potassium from the soil and upon decomposition it releases potassium in the available form. During rice-wheat, green manure application was found to increase available K at all the stages (Table 14), possibly due to release of CO_2 and organic acids from the green manure act on insoluble soil minerals, thereby releasing nutrients into the soil solution (Swarup, 1987). Further, it can be due to release of Fe^{2+} and Mn^{2-} under highly reduced conditions created by green manure (Katyal, 1977). The highest available K was observed during crop growth stages, possibly due to release of K from green manure and potassium added through fertilizers. Reduction in available K in the later stages can be attributed to fixation and crop removal. Greater positive balance (Fig. 3) was observed in orgnic manure (O_{180}) treated pots, possibly due to slow release of K into soil solution through decomposition.

In control treatments (I_0+O_0+I) high positive balance was observed due to additiion of K fertilizer and low crop removal as the growth was affected by non-availability of other nutrients. In organic (O_0) control neither K fertilizer nor manure was added and hence, greater negative balance was observed.

Green manure increased microbial biomass content (Table 15) due to release of nitrogen and other nutrients on decomposition in available form and availability of carbon source for the growth and development of microbial population in soil. Bolten *et al.* (1985) observed a 26.6% increase in microbial biomass with the continuous use of leguminous green manures over the application of chemical fertilizers. Increase in microbial biomass carbon as observed by Chander *et al.* (1997) with the inclusion of green manure crop in the millet-wheat-fallow rotation supports the importance of green manure in increasing the biomass carbon. Cultivation increased the biomass carbon possibly due to the favourable growing environment created by crop plants themselves and management of soil.

Due to the increase in the availability of nutrients and carbon source, increase in rate of application of manures and fertilizers increased the biomass (Fig. 4). Kukerja *et al.* (1991) also observed increase in microbial biomass with increasing applications of FYM. However, during crop growth stage biomass was more, possibly due to higher availability of nutrients, favourable environment created by crop cultivation and selective stimulation of microbes by rice-wheat. Lynch and Panting (1980) observed increase in soil biomass during the growht of a wheat crop and then decreased to an approximately constant amount. Application of nutrients through organic + inorganic source increased the biomass carbon. due to increased availability of nutrients and carbon source (Kukreja *et al.*, 1991). The microbial biomass carbon content in different treatments followed the order : Organic + Inorganic > Organic > Inorganic.

Measurement of soil respiration is one of the widely accepted approaches to study biological activities in soil. However, there is spatial and temporal variability of soil respiration in agricultural fields (Rochette *et al.*, 1991). Green manuring significantly increased the soil respiration (Table 16), presumably from decomposition activity on freshly incorporated green manure. The respiration was more in organic manured treatments followed by organic+inorganic and inorganic alone. Rao and Pathak (1996) also observed an increase in respiration of soil where organic matter was added into soil.

The respiration was more during crop growth either with or without green manure (Fig. 5). This coincides with the period of maximum growth of rice and wheat. Further, carbon dioxide output is positively affected by soil water content for similar temperatures (Kucera and Kirkham, 1971).

Dehydrogenase is a metabolic enzyme used to measure the metabolic activity of soil biomass. Green manuring increased the dehydrogenase activity (DHA) during rice-wheat (Table 17). This is in confirmity with the results obtained by Bolten *et al.* (1985). Further, DHA was more during crop growth stages. Microbial biomass and organic carbon was also high during crop growth stages. These results suggest that due to increase in microbial biomass and OC, dehydrogenase activity increases. Ladd and Paul (1973) also observed that increase in organic matter content and microbial population of soil increased the DHA of soil. Increasing rate of application of manures and fertilizers increased dehydrogenase activity (Fig. 6). However, it was observed that dehydrogenase activity increased with increasing amounts of organic manure but the increase was not in the same proportion as in the case of microbial biomass. This indicates that part of biomass is metabolically inactive. Similar results were reported by Kukreja *et al.* (1991).

The dehydrogenase activity was more in organic treatments followed by organic + inorganic and inorganic. There are several possible mechanisms for decreased microbial activity (DHA) including direct inhibitory effect of nitrogenous compounds, increasing retention of carbon and making carbon less available and a partial sterilization effect from the raised osmotic potential of the soil solution due to fertilizer salts. Any or all of these effects could be causing the significant decrease in dehydrogenase activity in the inorganic treatments as suggested by Cooper and Warman (1997). However, Kukreja *et al.* (1991) have suggested that nitrate and nitrite could serve as alternate electron acceptors and hence, DHA decreases.

With the addition of organic matter into the soil, microbial biomass carbon to orgnic carbon ratio (BC/OC) increases and *vice-versa*. Consequently, a constancy of the ratio is thus achieved, which is an indication of a system at a new equilibruim. It was observed that this ratio increased with the increase in organic carbon (Fig. 7). However, it was not proportionate. At higher organic carbon content the ratio increased at decreasing rate. This indicated that at higher organic carbon content the contribution of biomass to total organic carbon was low. However, in organic+inorganic treatments, the ratio increased with increase in organic carbon. Moreover, application of green manure didn't change the BC/OC ratio significantly (Table 18). These observations give the impression that making nutrients slowly available over a period of time, increases the contribution of biomass to organic carbon in soil. However, the same trend couldn't be observed in organic treatments due to non-availability of sufficient nutrients for microbial growth and in inorganic treatments, possibly due to toxicity of some of the nutrients made readily available through inorganic fertilizers (Kukreja *et al.*, 1991). However, significant difference observed in the ratio due to residual effect of green manuring at harvest stage of wheat, may be due to difference in management system for rice and wheat as the biomass is sensitive to change in management system than does organic carbon in the soil as suggested by Anderson and Domsch (1989).

Green manuring significantly increased the respiration to microbial biomass ratio (specific respiratory activity) during rice-wheat (Table 19) due to readily available carbon and nutrients in the soil on decomposition. The ratio increased with increase in the rate of manures and fertilizers but later it decreased. Further, with increase in biomass carbon the ratio increases at decreasing rate (Fig. 8). This is due to the fact that increase in microbial biomass with higher levels of carbon consists of more dormant cells. Campbell *et al.* (1991) also observed that the application of manures increased the microbial biomass and the specific respiratory activity decreased with increasing amounts of microbial biomass in soil. These results indicate that soil microbial population is active at an optimal level of manures and fertilizers, and becomes dormant with further increase in doses. Hence, overdose of nutrients in any form will not be useful to maintain the active biomass.

5.3 Yield

Green manuring significantly increased the grain yield of both rice (Fig. 9) and wheat (Fig. 10) due to better physical, chemical and biological environment created by it (Table 20). Similar findings were reported by Singh *et al.* (1992) and Ventura and Watanabe (1992). However, wheat yield was lower than rice possibly due to higher bulk density after rice harvest which retarded the rate of root extension and development as suggested by Meelu *et al.* (1979) and Kar *et al.* (1997). Yield in organic control treatment was significantly lower than the other two control treatments, due to no N, P and K addition as the nutrient deficiency symptoms and low growth are seen (Plate 1 to 4). The highest grain yield was observed (Fig. 15 and 16) in organic + inorganic @ nitrogen equivalent to 180 kg ha^{-1} along with green manure. This clearly shows the importance of applying nutrients through organic + inorganic sources which will reduce the nutrient losses, make nutrient available at required rate and time. Further, the need to apply green manure to substitute inorganic fertilizers. The same was observed by Tiwari *et al.* (1995). However, application of organic manure alone at the same nitrogen equivalent levels didn't increase the yield significantly. Hence, organic manure alone can not meet the nutrient demand of rice-wheat, to sustain the productivity on par with either inorganic sources or organic + inorganic sources.

5.4 Soil quality indicators in the field study

Rice followed by wheat is a predominant sequence among the rice based cropping systems in the Indo-Gangetic plains in general and Karnal district of Haryana in particular. It has saline and alkaline soils and the soil productivity influenced by different agronomic management practices being followed by farmers.

The soil reaction (Table 21) varied from slightly saline to alkaline and this is ascribed to difference in management practices including leaching and green manuring practiced by farmers. At locations 1 and 2 (L1 and L2) the pH was found to be low, because of green manuring. In general, after rice-wheat, the pH of soil decreased, possibly due to the effect of flooding and acid forming fertilizers being used in crop production. The salt content of soil (EC) varied from 0.20 to 0.41 (dSm^{-1}) at various locations (Table 22). The lowest was observed in L2, possibly due to green manuring. The lower EC after rice-wheat than initial values might be due to crop removal and leaching. The decrease in EC after an initial rise under flooded field conditions may be due to reprecipitation of Fe^{2+} and Mn^{2+} and consequent adsorption of other cations on the exchange sites, decrease in PCO_2, and decomposition of organic acids (Ponnamperuma, 1972). However, the bulk density of soil did not show any marked change and the differences among various locations were minimal possibly due to short observation period as it was not sufficient to influence a change in bulk density of the soil (Table 23).

The organic carbon content of soil varied owing to difference in management practices. At location 17, lowest organic carbon was observed (Table 24) possibly due to low level of manures and fertilizers management. In general, organic carbon was maintained or increased in rice-wheat cropping system possibly because of incorporation of residue into the soil. However, Mandal *et al.* (1991) observed a decline in organic carbon after 14 years of continuous cropping except FYM added treatment.

Total nitrogen content of soil (Table 25) is important as it reflects the C:N ratio of soil which in turn decides the mineralisation of nutrients. At some locations it decreased possibly due to heavy demand for nitrogen by crops and low level of replenishment through organic and inorganic sources. This view can be supported from the fact that at some locations, which are well managed, the total nitrogen content at the end of rice-wheat slightly increased. The available nitrogen after rice-wheat decreased by varying degrees at different locations, possibly due to crop removal and losses (Table 26). In some poorly managed soils, the decrease in available nitrogen may be due to low level of replenishment.

However, except at locations 14 and 15 (L14 and L15) the available phosphorus showed a positive balance (Table 27). Manganese and iron reduction and subsequent phosphorus mobilisation was more in flooded rice soil than those which were not (Willett and Malafant, 1985). As in the case of total and available nitrogen L17 had lowest phosphorus content. This indicates that phosphorus is not limiting in rice-wheat areas of Karnal.

The level of potassium possibly limits the available K and its balance after rice-wheat. At locations 1 to 10, there was a positive balance when compared to initial value. However, at L12 to L17 it was *vice-versa* (Table 28). Prasad and Rokima (1991) from their nutrient balance sheet approach in rice-wheat cropping system found that nitrogen and phosphorus had positive and potassium had negative balance in soil. Removal of K was more than that applied through treatments. The amount of N, P and K declined in plots not fertilized with N, P and K (Prasad and Sinha, 1981). Application of FYM and BGA led to a greater accumulation of available nitrogen than that of fertilizers alone. The highest accumulation of K was observed in the treatments of NPK (100%) + FYM + BGA (Maurya and Ghosh, 1972). Hence, the nutrient status at various locations clearly suggest that the positive or negative balance of nutrients is influenced by management practices being followed by farmers which in turn govern the yield and fertility of soils.

The microbial biomass carbon content increased due to cultivation and the degree of this effect was more in lower fertility levels (Table 29). This may be due to non-availability of nutrients for microbial growth and at higher fertility levels biomass was not influenced much by cultivation practices. This is in confirmity with the results obtained by Lynch and Panting (1980). However, microbial biomass carbon content increased with increase in organic carbon in soil. This indicates that availability of carbon source apart from nutrients are essential for biomass content in the field. Hence, highly fertilized soil too, can not have much biomass until otherwise, it is supplied through required carbon source. Further, from the dehydrogenase activity it is clear that soil with low microbial biomass had low dehydrogenase activity and at the same time with very high biomass content the dehydrogenase activity was not proportionate indicating that, part of microbial population is inactive or dormant (Table 31). At location 3, dehydrogenase activity was more probably due to better physico, chemical and biological environment (L3 was green manured). The soil dormant biomass becomes active in response to the inputs of substrates in the form of root exudates, decomposing roots and crop residues (Lynch and Panting, 1980). This explains the more active biomass during crop growth stages.

The respiration of soil increased with cultivation and organic carbon and biomass, which in turn affected by fertility of the soil (Table 30). At low level of management (at L16 & L17) the biomass was lower and hence, respiration was lower.

The increase in biomass to organic carbon ratio due to cultivation can be attributed to increase in biomass carbon (Table 32). This rise in biomass carbon over organic carbon is seen as a transient rather than an absolute phenomenon and is believed to be due to easily available carbon fraction of the introduced organic material (Anderson and Domsch, 1989). At harvest stage of wheat the ratio was more, because of increase in biomass and its contribution to total organic carbon. At L15, the lowest value was observed possibly due to low biomass carbon as a result of poor soil management, which is reflected further in the respiration, biomass, fertility status and yield. The differences in biomass to organic carbon ratio is mostly because of difference in cropping management than other reasons (Anderson and Domsch, 1989).

The respiration to microbial biomass ratio will be lower (Table 33) as a result of either increase in microbial biomass or increase in activity of microbial biomass in a favourable soil conditions. The ratio was higher at initial stage and decreased at harvest stages of rice and wheat. This is possibly because of dormant microbial population at initial stages as the soil was dry and hot. Further, during rice-wheat due to better soil environmental conditions created by management activities the soil microbial population became more active. The same reason was suggested by Campbell *et al.* (1992).

The results of all biological activity indicates that it varies with location due to several factors. Both osmotic and ionic effects of salts and limited carbonaceous substrates, as suggested by Rao and Pathak (1996) can explain the low biological activity in some locations, which are salt affected.

5.5 Soil quality indices

The soil physical, chemical and biological properties interact in a complex way to give a soil its quality or capacity to function. Hence, soil quality must be inferred from measuring changes in its attributes of the ecosystem, referred to as indicators. Only a minimum data set consisting of a core set of attributes encompassing physical, chemical and biological soil properties are selected for soil quality assessment (Larson and Pierce, 1991).

As the rice-wheat system requires different set of edaphic condition, in the present investigation three methods to compute soil quality index have been proposed. Because, different kinds of land uses may require increased capacities of certain soil functions and thus, require certain indicators over others for assessment (Seybold *et al.*, 1998). These methods quantify the measured soil quality indicators. These indices have also been used to measure the changes in soil quality over time. These indices varied in sensitivity to predict the changes in soil quality indicators because of different methods used to compute them. Method-I was sensitive as it includes all the observed soil quality parameters with their respective ratings. Hence, Method-I can be used to predict the changes in soil quality in rice-wheat with different edaphic requirements. In Method-II, partial R^2 values of indicators were multiplied with their respective scores. Because of this, it can also be used to predict the changes. Further, this method reflected relative weightage of soil quality parameters in rice-wheat cropping system. In, Method-III standardised regression co-efficient was used and all the indicators were used to compute the index without considering their relative importance (Some of the non-significant indicators were also used to compute the index). Hence, this method was less sensitive in predicting the changes in rice-wheat cropping system.

Soil quality index was more in green manuring treatments due to favourable physical, chemical and biological soil environment created by green manuring. Moreover, the soil quality index is a combined value and change in each of indicator values also reflected in it. This also explains the low and high observed values in the experiment. In general better soil condition was created in organc+inorganic treatments @ nitrogen equivalent to 180 kg ha^{-1}, as it is reflected in the high soil quality index values.

In control treatments negative balance was observed (Fig. 11). This is due to deterioration of soil quality with imbalance in fertilization in rice-wheat cropping system. However, green manuring resulted in favourable balance in soil quality index. Hence, this envisages the need to green manuring in rice-wheat to maintain the soil quality.

The set of indicators used for assessing soil quality can vary from location to location depending on the kind of land or land used, soil function, and the soil forming factors (Arshad and Coen, 1992). Method-I was used to compute the soil quality index for different locations (Table 35). In general locations 1, 2 and 3 had high values, possibly due to better soil management. This also explains the net positive/negative change in soil quality index at some locations (Fig. 12). However, because of the diversity in potential land uses, the soil quality evaluations should be viewed as relational rather than absolute. This recognises that soils are different and that for a specific function, the quality of soils can be different without necessarily being limiting (Karlen *et al.*, 1997).

5.6 Sustainability of rice-wheat cropping system

Sustainability of land management can be determined by way of assessing the soil quality indicators (Doran *et al.*, 1994). Soil quality indices have been computed using three methods (Table 34 and 35). Using the changes in the soil quality index over a period of time sustainability of rice-wheat cropping system can also be monitored.

If the changes in soil quality index is positive, the soil can be regarded as improving or aggrading in quality. This trend was observed at location-1 (Fig. 14). Conversely, if the trend line is negative, then quality of soil is degrading, as observed at location-8. A no-change trend would indicate a sustaining system. This trend was observed at location-13. Seybold *et al.* (1998) stated that calculating the slope of the trend line is a way of quantifying change in soil quality.

This approach, however, doesn't provide immediate assessment of soil quality and it requires measurement of soil quality indicators for at least two points in time. Further, this approach may not be much useful, if a soil is functioning at the highest level attainable and can not improve and if it is functioning at its lowest level and can not go lower. In both these cases it showed a trend of no change or static, indicating a sustaining system. However, their qualities are completely different. Hence, it is desirable to show the state of soil quality on a normalized scale also. But normally in rice-wheat system, even with minimum management care or input intensive cropping, this approach is fairly good to assess the soil quality indicators.

The indices can be used to monitor the sustainability in different land management systems i.e., organic, inorganic and organic + inorganic. In addition to this, different systems can also be compared. However, to have better reliability, this needs observations over a period of time. This method was used to compare different tillage systems like conventional, no-till and organic by McQuaid and Olson (1997). Compared to other methods of monitoring sustainability of rice-wheat system, this approach is better, as it includes important soil quality indicators and it's relative weightage.

So. this approach can be used not only to monitor the sustainability but also to compare the sustainability of rice-wheat cropping system at different places. However. soil quality assessment for sustainability can be carried out by measuring the current state of an indicator and comparing the results to known or desired values. This approach can also be used to follow temporal trends associated with specific land-use decisions (Karlen *et al.*, 1997).

SUMMARY AND CONCLUSIONS

Pot culture experiment was conducted to study the effect of manures and fertilizers on different soil quality indicators with rice-wheat cropping system. The soil quality indicators were assessed at four different growth stages during rice-wheat *viz.*, 45 DAT of rice, at harvest stage of rice, 60 DAS of wheat and at harvest stage of wheat. The effect of green manure on various soil quality indices and yield of rice and wheat were also studied. Field study was conducted in Karnal to assess the soil quality indicators and to monitor sustainability of rice-wheat cropping system. Soil quality indices were computed using three methods and the sustainability of rice-wheat cropping system was monitored. From these studies, the salient findings are presented below :

1. Green manuring had favourable effect on different soil quality indicators measured in pot experiment and in turn maintaining the overall quality of soil in rice-wheat cropping system.

2. Various management systems like organic, inorganic and organic+inorganic differed in their effect on soil quality indicators.

3. The relative importance and their respective weightage of different soil quality indicators varied with crops, time of sampling and management systems.

4. Study of balance of nutrients in pot experiment, after rice and wheat is a good measure of fertility status of soil in all the treatments.

5. There was, in general, a build up of phosphorus, in phosphorus applied treatments (inorganic and organic + inorganic) in the order of control > nitrogen equivalent to 120 kg ha^{-1} > 180 kg ha^{-1}.

6. Organic carbon content increased with green manuring and increase in the rate of organic manures.

7. Biomass carbon and respiration increased with increase in organic carbon. However, the increase was not proportional at all stages.

8. At higher organic carbon and biomass carbon content, part of the soil microbial population was inactive.

9. Increasing only organic carbon without increase in the active soil microbial population was of no use. Hence, optimum fertilizers and manures preferably with organic + inorganic combination was found to be good.

10. Intensive cropping without organic manures and imbalance in fertilization caused reduction in soil quality values.

11. Green manuring significantly increased the yield of rice and wheat (17.8 to 22.3 g pot^{-1} in rice and 11.9 to 13.6 g pot^{-1} in wheat).

12. The grain yield was lower in organic system than in inorganic. However, overall soil quality was better in organic system.

13. Rice yield was more (29.3 g pot^{-1}) in organic + inorganic treatment (N equivalent to 180 kg ha^{-1}) followed by inorganic (29.2 g pot^{-1}) and organic (21.9 g pot^{-1}). Whereas in wheat, yield was more in organic + inorganic (N equivalent to 180 kg ha^{-1}) treatment (19 g pot^{-1}) followed by organic (18.1 g pot^{-1}) and inorganic (17.5 g pot^{-1}).

14. Quantification of soil quality indicator values gave better understanding of soil quality and sustainability than with any single indicator including yield.

15. There were three methods to compute the soil quality indices, which were used to measure the soil quality and sustainability of rice-wheat cropping system in pot culture experiment and in field study. Among the three methods, Method-I and II were found to be better as these are sensitive to edaphic changes in the rice-wheat cropping system.

16. Higher doses of inorganic fertilizers (I_{180}) aimed to increase the yield caused reduction in soil quality index values. However, the quality was maintained by green manuring.

17. Based on the soil quality index computed for different locations (Method-I) in rice-wheat cropping system the sustainability of rice-wheat was monitored. At location-1 the system is aggrading (2.000 to 2.462), at location-8 it is degrading (2.000 to 1.923) and at location-13 it is sustaining (2.000 to 2.077). This approach could be used to monitor and compare the sustainability of rice-wheat cropping system under different management systems and at different places.

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* Original not seen.

Appendix-1

Scores for observed soil quality parameters in pot culture experiments (After rice)

Treat-ments	pH	EC	Bulk	OC	BC	Tot N	Avl. N	Avl. P	Avl. K	DHA	RES	BC/ OC	R/ BC
G1R1	3	3	3	2	1	3	1	2	2	1	1	1	1
G2R1	3	3	3	2	2	3	1	2	3	2	2	1	3
G3R1	3	3	3	3	2	3	2	3	3	2	2	1	1
G4R1	3	3	3	2	1	3	1	2	2	1	1	1	3
G5R1	3	3	3	2	2	3	1	3	3	1	2	1	3
G6R1	3	3	3	2	2	3	2	3	3	2	1	1	3
G7R1	3	3	3	2	1	3	1	2	2	1	1	1	1
G8R1	3	3	3	2	2	3	1	3	3	2	2	3	3
G9R1	3	3	3	2	2	3	2	3	3	2	2	3	1
1R1	2	3	3	2	1	3	1	1	2	1	1	1	1
2R1	2	3	3	2	2	3	1	2	2	1	2	1	3
3R1	2	3	3	3	2	3	2	2	3	1	1	1	3
4R1	3	3	3	2	1	3	1	2	3	1	1	1	1
5R1	3	3	3	2	2	3	1	3	2	1	1	1	3
6R1	3	3	3	2	2	3	1	3	2	1	1	1	3
7R1	3	3	3	2	1	3	1	2	2	1	1	1	1
8R1	3	3	3	2	2	3	1	3	2	1	1	3	3
9R1	3	3	3	2	2	3	2	3	2	1	2	3	1
G1R2	3	3	3	2	1	3	1	2	2	1	1	1	1
G2R2	2	3	3	3	2	3	1	2	2	2	2	1	1
G3R2	2	3	3	3	2	3	2	3	3	2	1	1	1
G4R2	3	3	3	2	1	3	1	2	2	1	1	1	1
G5R2	3	3	3	2	2	3	1	3	2	1	2	1	3
G6R2	3	3	3	2	2	3	2	3	2	2	1	1	3
G7R2	3	3	3	2	1	3	1	2	2	1	1	1	1
G8R2	3	3	3	2	2	3	1	3	3	1	2	3	1
G9R2	3	3	3	3	2	3	2	3	3	2	2	3	1
1R2	3	3	3	2	1	3	1	1	2	1	1	1	1
2R2	3	3	3	2	2	3	1	2	3	1	2	1	3
3R2	3	3	3	2	2	3	2	2	3	2	2	1	3
4R2	3	3	3	2	1	3	1	2	3	1	1	1	1
5R2	3	3	3	2	2	3	1	3	2	1	1	1	3
6R2	3	3	3	2	2	3	2	3	2	1	1	1	3
7R2	3	3	3	2	1	3	1	2	3	1	1	1	1
8R2	3	3	3	2	2	3	1	3	3	1	2	3	3
9R2	3	3	3	2	2	3	2	3	3	1	2	3	1
G1R3	3	3	3	2	1	3	1	2	2	1	1	1	1
G2R3	1	3	3	2	2	3	1	2	3	2	2	1	1
G3R3	2	3	3	3	2	3	2	3	3	2	2	1	1
G4R3	3	3	3	2	1	3	1	2	2	1	1	1	1
G5R3	3	3	3	2	2	3	1	3	3	1	2	1	3
G6R3	3	3	3	2	2	3	2	3	2	2	1	1	3
G7R3	3	3	3	2	1	3	1	2	2	1	1	1	1
G8R3	3	3	3	2	2	3	1	3	3	1	2	3	1
G9R3	3	3	3	2	2	3	2	3	3	2	2	3	1
1R3	2	3	3	2	1	3	1	1	2	1	1	1	1
2R3	2	3	3	2	2	3	1	2	2	1	2	1	3
3R3	2	3	3	2	2	3	1	2	2	1	2	1	3
4R3	3	3	3	2	1	3	1	2	3	1	1	1	1
5R3	3	3	3	2	2	3	1	3	2	1	1	1	3
6R3	3	3	3	2	2	3	2	3	2	1	1	1	3
7R3	3	3	3	2	1	3	1	2	3	1	1	1	1
8R3	3	3	3	2	2	3	1	3	3	1	1	3	3
9R3	3	3	3	2	2	3	2	3	3	1	2	3	1

G denotes addition of green manure otherwise no addition.

R denotes replication

1 - O_0; 2 - $O_{[illegible]}$; 3 - $O_{[illegible]}$; 4 - I_0; 5 - I_{120}; 6 - I_{180}; 7 - $O_{[illegible]}+I_{[illegible]}$; 8 - $O_{60}+I_{60}$; 9 - $O_{90}+I_{90}$.

Appendix-2

Scores for observed soil quality parameters in pot culture experiments (After wheat)

Treat-ments	pH	EC	Bulk	OC	BC	Tot. N	Avl. N	Avl. P	Avl. K	DHA	RES	BC/OC	R/BC
G1R1	3	3	3	2	2	3	1	2	2	1	1	1	1
G2R1	3	3	3	2	2	3	2	2	3	2	2	3	3
G3R1	3	3	3	3	2	3	2	3	3	2	2	3	1
G4R1	3	3	3	2	1	3	1	2	3	1	1	1	1
G5R1	3	3	3	2	2	3	1	3	3	1	2	3	3
G6R1	3	3	3	2	2	3	2	3	2	2	2	3	3
G7R1	3	3	3	2	1	3	1	2	3	1	1	1	3
G8R1	3	3	3	2	2	3	2	3	3	2	2	3	1
G9R1	3	3	3	2	2	3	2	3	3	2	2	3	1
1R1	2	3	3	2	1	3	1	1	2	1	1	1	1
2R1	2	3	3	2	2	3	1	2	2	1	2	1	3
3R1	1	3	3	3	2	3	2	2	3	2	1	1	3
4R1	2	3	3	2	1	3	1	2	3	1	1	1	1
5R1	2	3	3	2	2	3	1	3	2	1	1	1	3
6R1	2	3	3	2	2	3	1	3	2	1	1	1	3
7R1	2	3	3	2	1	3	1	2	2	1	1	1	1
8R1	2	3	3	2	2	3	1	3	2	1	1	3	1
9R1	3	3	3	2	2	3	2	3	2	1	2	3	1
G1R2	2	3	3	2	2	3	1	2	2	1	1	1	1
G2R2	2	3	3	3	2	3	1	2	2	2	2	3	1
G3R2	2	3	3	3	2	3	2	3	3	2	2	1	1
G4R2	2	3	3	2	1	3	1	2	3	1	1	1	1
G5R2	2	3	3	2	2	3	1	3	2	1	2	1	3
G6R2	1	3	3	2	2	3	2	3	2	1	1	1	3
G7R2	2	3	3	2	1	3	1	2	3	1	1	1	1
G8R2	3	3	3	3	2	3	1	3	3	2	2	3	1
G9R2	3	3	3	3	2	3	2	3	3	2	2	3	1
1R2	3	3	3	2	1	3	1	1	2	1	1	1	1
2R2	3	3	3	2	2	3	1	2	2	1	2	1	3
3R2	3	3	3	2	2	3	2	3	3	2	2	1	3
4R2	3	3	3	2	1	3	1	2	3	1	1	1	1
5R2	3	3	3	2	2	3	1	3	3	1	1	3	3
6R2	3	3	3	2	2	3	2	3	3	1	1	3	3
7R2	3	3	3	2	1	3	1	2	2	1	1	1	1
8R2	3	3	3	2	2	3	2	3	2	1	2	3	3
9R2	3	3	3	2	2	3	2	3	2	1	2	3	1
G1R3	1	3	3	2	2	3	1	2	2	1	1	1	1
G2R3	3	3	3	2	2	3	2	2	3	2	2	3	1
G3R3	3	3	3	3	2	3	2	3	3	2	2	3	1
G4R3	2	3	3	2	1	3	1	2	3	1	1	1	1
G5R3	3	3	3	2	2	3	1	3	3	1	2	1	3
G6R3	3	3	3	2	2	3	2	3	2	2	2	1	3
G7R3	3	3	3	2	1	3	1	2	3	1	1	1	1
G8R3	3	3	3	2	2	3	2	3	3	2	2	3	1
G9R3	3	3	3	3	2	3	2	3	3	2	2	3	1
1R3	2	3	3	2	1	3	1	1	2	1	1	1	1
2R3	1	3	3	2	2	3	1	2	2	1	2	1	3
3R3	3	3	3	2	2	3	2	2	3	2	2	1	3
4R3	2	3	3	2	1	3	1	2	3	1	1	1	1
5R3	2	3	3	2	2	3	1	3	3	1	1	1	3
6R3	3	3	3	2	2	3	2	3	2	1	1	3	3
7R3	1	3	3	2	1	3	1	2	3	1	1	1	1
8R3	3	3	3	2	2	3	1	3	2	1	2	3	1
9R3	3	3	3	2	2	3	2	3	2	1	2	3	1

G denotes addition of green manure otherwise no addition.
R denotes replication
1 - O_0; 2 - O_{120}; 3 - O_{180}; 4 - I_0; 5 - I_{120}; 6 - I_{180}; 7 - O_0+I_0; 8 - $O_{60}+I_{60}$; 9 - $O_{90}+I_{90}$.

Appendix-3

Scores for observed soil quality parameters (field observation)

Locations	pH	EC	Bulk	OC	BC	Tot. N	Avl. N	Avl. P	Avl. K	DHA	RES	BC/ OC	R/ BC
Initial values													
L1	3	3	2	2	2	3	1	3	3	1	1	1	3
L2	3	3	2	2	2	3	2	3	3	2	1	1	3
L3	2	3	3	3	2	3	2	3	3	2	1	1	3
L4	2	3	2	3	2	3	1	3	3	2	1	1	3
L5	2	3	2	2	2	3	1	3	3	1	1	1	3
L6	2	3	2	2	2	3	1	3	3	1	1	1	3
L7	1	3	2	2	[illegible]	3	1	3	3	1	1	1	3
L8	2	3	2	2	2	3	1	3	3	1	1	1	3
L9	2	3	2	2	2	3	2	3	3	1	1	1	3
L10	2	3	2	2	[illegible]	3	1	3	3	1	1	1	3
L11	2	3	2	2	[illegible]	3	1	3	3	1	1	1	3
L12	2	3	2	3	2	3	1	3	3	2	1	1	3
L13	2	3	2	2	2	3	1	3	3	1	1	1	3
L14	2	3	2	2	2	3	1	3	3	1	1	1	3
L15	2	3	2	2	2	3	1	3	3	1	1	1	3
L16	2	3	2	2	2	3	1	3	3	1	1	1	3
L17	2	3	2	2	2	3	1	3	3	1	1	1	3
After Rice													
L1	3	3	2	2	2	3	2	3	3	2	1	1	3
L2	3	3	2	2	2	3	2	3	3	2	2	1	3
L3	2	3	3	3	2	3	2	3	3	2	2	1	3
L4	2	3	2	3	2	3	1	3	3	2	2	1	1
L5	2	3	2	2	2	3	1	3	3	2	1	1	3
L6	2	3	2	2	2	3	1	3	3	2	1	1	3
L7	1	3	2	2	2	3	1	3	3	1	1	1	3
L8	2	3	2	2	2	3	1	3	3	1	1	1	3
L9	2	3	2	2	2	3	2	3	3	2	1	1	3
L10	2	3	2	2	2	3	1	3	3	1	1	1	3
L11	2	3	2	2	2	3	1	3	3	1	1	1	3
L12	2	3	2	3	2	3	2	3	3	2	2	1	[illegible]
L13	2	3	2	2	2	3	1	3	3	2	1	1	3
L14	2	3	2	2	2	3	1	3	3	1	1	1	3
L15	2	3	2	2	2	3	1	3	3	1	1	1	3
L16	2	3	2	2	2	3	1	3	3	1	1	1	3
L17	2	3	2	2	2	3	1	3	3	1	1	1	3
After wheat													
L1	3	3	2	3	2	3	2	3	3	2	2	1	3
L2	3	3	2	3	2	3	2	3	3	2	2	1	3
L3	2	3	3	3	2	3	2	3	3	2	2	1	1
L4	2	3	2	3	2	3	2	3	3	2	2	1	1
L5	2	3	2	2	2	3	1	3	3	2	1	1	3
L6	2	3	2	2	2	3	1	3	3	2	1	1	3
L7	1	3	2	2	2	3	1	3	3	2	1	1	3
L8	2	3	2	2	2	3	1	3	3	1	1	1	1
L9	2	3	2	3	2	3	2	3	3	2	1	1	1
L10	2	3	2	2	2	3	1	3	3	1	1	1	3
L11	2	3	2	2	2	3	1	3	3	1	1	1	3
L12	2	3	2	2	2	3	1	3	3	1	1	1	3
L13	2	3	2	2	2	3	1	3	3	1	1	1	3
L14	2	3	2	2	2	3	1	3	3	1	1	3	3
L15	2	3	2	2	2	3	1	3	3	1	1	3	3
L16	2	3	2	2	2	3	1	3	3	1	1	3	3
L17	2	3	2	2	2	3	1	3	3	1	1	3	3

Appendix-4

Partial R^2 values of soil quality parameters (Wi)

Sl.No.	Variables	Partial R^2 values				
		Pot culture experiment		Field experiment		
		After rice	After wheat	Initial	After rice	After wheat
1.	pH	0.0048	0.0044	0.0234	0.5704	0.0254
2.	EC	0.0052	0.0053	0.5747	0.0314	0.0386
3.	BD	0.0020	0.0044	0.0234	0.0314	0.0254
4.	OC	0.0063	0.0044	0.0234	0.0314	0.0547
5.	BC	0.0082	0.0044	0.0234	0.0314	0.0254
6.	Tot. N	0.0063	0.0035	0.0234	0.0325	0.0254
7.	Avl. N	0.0009	0.8157	0.0234	0.0314	0.1084
8.	Avl. P	0.8570	0.0053	0.0234	0.0314	0.0254
9.	Avl. K	0.0395	0.0052	0.0234	0.0314	0.0139
10.	DHA	0.0030	0.0035	0.0234	0.0314	0.1516
11.	RES	0.0023	0.0044	0.0544	0.0314	0.0254
12.	BC/OC	0.0063	0.0035	0.1369	0.0314	0.0254
13.	R/BC	0.0206	0.0359	0.0234	0.0835	0.0254

Note : The partial R^2 values explains the total variability in grain yield (model R^2 = 1.000)
Variables are significant at 15 % level.

Appendix-5

Standardised regression co-efficient of soil quality parameters (BETAi)

Sl.No.	Variables	Standardised regression co-efficient values				
		Pot culture experiment		Field experiment		
		After rice	After wheat	Initial	After rice	After wheat
1.	pH	0.0048	0.0004	0.0206	0.5704	0.0033
2.	EC	0.0052	0.0053	0.5740	0.0037	0.4068
3.	BD	0.0012	0.0001	0.0743	0.0968	0.0046
4.	OC	0.0001	0.0003	0.0002	0.0021	0.0451
5.	BC	0.0082	0.0005	0.0174	0.0867	0.0009
6.	Tot. N	0.0007	0.0035	0.0543	0.0027	0.0146
7.	Avl. N	0.0312	0.9150	0.0035	0.0002	0.1084
8.	Avl. P	0.8578	0.0053	0.0002	0.0208	0.0127
9.	Avl. K	0.0395	0.0052	0.0223	0.0662	0.1278
10.	DHA	0.0030	0.0035	0.0011	0.0008	0.1516
11.	RES	0.0023	0.0001	0.0544	0.0065	0.0008
12.	BC/OC	0.0030	0.0035	0.1369	0.0515	0.0092
13.	R/BC	0.0206	0.0359	0.0074	0.0835	0.0018
Model R^2 values		0.9776	0.9793	0.9672	0.9917	0.8875